VOLUME 85 NO. IR4
DECEMBER 1959
PART 1

JOURNAL of the

Irrigation and Drainage Division

PROCEEDINGS OF THE
AMERICAN SOCIETY
OF CIVIL ENGINEERS

BASIC REQUIREMENTS FOR MANUSCRIPTS

This Journal represents an effort by the Society to deliver information to the reader with the greatest possible speed. To this end the material herein has none of the usual editing required in more formal publications.

Original papers and discussions of current papers should be submitted to the Manager of Technical Publications, ASCE. Authors should indicate the technical division to which the paper should be referred. The final date on which a discussion should reach the Society is given as a footnote with each paper. Those who are planning to submit material will expedite the review and publication procedures by complying with the following basic requirements:

1. Titles should have a length not exceeding 50 characters and spaces.

2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

4. The author's full name, Society membership grade, and footnote reference stating present employment should appear on the first page of the paper.

5. Mathematics are reproduced directly from the copy that is submitted. Because of this, it is necessary that capital letters be drawn, in black ink, ⅛-in. high (with all other symbols and characters in the proportions dictated by standard drafting practice) and that no line of mathematics be longer than 6½-in. Ribbon copies of typed equations may be used but they will be proportionately smaller on the printed version.

6. Tables should be typed (ribbon copies) on one side of 8½-in. by 11-in. paper with a 6½-in. by 10½-in. invisible frame. Small tables should be grouped within this frame. Specific reference and explanation should be made in the text for each table.

7. Illustrations should be drawn in black ink on one side of 8½-in. by 11-in. paper within an invisible frame that measures 6½-in. by 10½-in.; the caption should also be included within the frame. Because illustrations will be reduced to 69% of the original size, the capital letters should be ⅛-in. high. Photographs should be submitted as glossy prints in a size that is less than 6½-in. by 10½-in. Explanations and descriptions should be made within the text for each illustration.

8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

Further information concerning the preparation of technical papers is contained in the "Technical Publications Handbook" which can be obtained from the Society.

Reprints from this Journal may be made on condition that the full title of the paper, name of author, page reference (or paper number), and date of publication by the Society are given. The Society is not responsible for any statement made or opinion expressed in its publications.

This Journal is published quarterly by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal. Second-class postage paid at Ann Arbor, Michigan.

Subject and author indexes, with abstracts, are published at the end of each year for the Proceedings of ASCE. The index for 1958 was published as Proc. Paper 1891; indexes for previous years are also available.

EM,HW,IR,WW.

Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

IRRIGATION AND DRAINAGE DIVISION
EXECUTIVE COMMITTEE
John H. Bliss, Chairman; Kenneth Q. Volk, Vice-Chairman;
N. A. Christensen; Herbert E. Prater; William W. Donnan, Secretary

COMMITTEE ON PUBLICATIONS
Dean F. Peterson, Jr., Chairman; Charles L. Barker;
Harry F. Blaney, Sr.; Eldred R. Harrington; Calvin C. Warnick

CONTENTS

December, 1959

Papers

	Page
Artificial Recharge of Ground Water Reservoirs in California by Raymond C. Richter and Robert Y. D. Chun	1
This Problem of Water Rights by Robert L. Smith	29
Legal Aspects of Ground Water Utilization by Robert O. Thomas	41
Evaluating Furrow and Corrugation Irrigation by Dell G. Shockley	65
Discussion	73

Copyright 1959 by the American Society of Civil Engineers.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

ARTIFICIAL RECHARGE OF GROUND WATER RESERVOIRS IN CALIFORNIA

Raymond C. Richter[1] and Robert Y. D. Chun,[2] M. ASCE

ABSTRACT

This paper discusses some of the present needs for practice of artificial recharging of ground water in California; describes the major types of artificial recharge projects used in California; summarizes the extent of artificial recharge activities in California; and reviews some of the important factors related to selection of artificial recharge project sites with particular emphasis on infiltration rates.

INTRODUCTION

California is richly endowed with extensive ground water reservoirs. Since the turn of the century, draft on ground water supplies in California has increased at an accelerated rate. In many areas, particularly in central and southern California, extractions of ground water are now far in excess of net natural recharge. Where these conditions exist, ground water is being withdrawn from storage, water levels are declining, and other adverse effects associated with ground water overdraft are rapidly developing, including adverse salt balance and sea water intrusion.

The primary purpose of most artificial recharge activities in California is threefold: (1) combat adverse conditions resulting from overdevelopment of ground water; (2) increase conservation of local runoff; and (3) increase the amount of ground water available for use. Many specific objectives are encompassed within this purpose, including:

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2281 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. IR 4, December, 1959.

1. Superv. Eng. Geologist, Calif. Dept. of Water Resources - Sacramento Calif.
2. Associate Hydr. Engr., Calif. Dept. of Water Resources - Los Angeles, Calif.

1. Augmentation of the recharge to the ground water reservoir to compensate for man's activities which tend to reduce natural recharge such as:
   a. lining of steam channels for flood protection;
   b. discharging of sewage and industrial wastes of suitable quality to saline waters through sewage disposal systems;
   c. sealing of natural recharge areas with impervious sidewalks, streets, airports, parking lots, and buildings;
   d. exporting of local surface runoff which might otherwise percolate naturally in stream channels;
2. Conjunctive operation of surface and ground water reservoirs;
3. Reduction of ground water overdraft;
4. Control of sea water intrusion and local bodies of poor quality water;
5. Control or prevention of adverse salt balance;
6. Maintenance or raising of water levels to avoid increased water well construction, pumping costs, and obselescence of equipment and wells;
7. Reduction or cessation of land subsidence problems in areas where overdraft results in compaction of sediments.

The term artificial recharge, as used in California, is defined as the process of replenishment of ground water storage through works provided primarily for that purpose. It should be noted that intent is an essential element in this definition. Many projects designed for disposal of return irrigation waters, sewage, cooling water, or other wastes will also augment ground waters. However, ground water replenishment is generally incidental to the primary function of these works, and they are not considered true artificial recharge projects.

Some of the more important aspects of artificial recharge in California discussed in this paper include: methods of artificial recharge; artificial recharge activities in California; and factors related to selection of project sites with particular emphasis on infiltration rates.

Methods of Artificial Recharge and Some Design Criteria

Artificial replenishment of ground waters is accomplished primarily through works designed to maintain infiltration rates, increase the wetted area, and to increase the period of infiltration beyond that which exists under natural conditions. Although no two projects are identical, most of them utilize variations or combinations of the following basic methods: basins, modified stream bed, pits, ditches and furrows, flooding, and injection wells. These methods can all be used in conjunction with upstream surface reservoirs, which are sometimes provided to regulate flood flows, to temporarily store flood waters and limit flows to the absorptive capacity of the spreading works, and to remove a large portion of the detritus.

In most recharge projects, water is conveyed various distances from a source, such as an open channel or closed conduit, to the artificial recharge project. Usually adequate facilities are provided for controlled diversions. In open channels, the diversion structures have ranged from a simple earth

or rock dam thrown across a stream channel with little if any control of diversion, to a well designed gate-type installation which includes features to control the amount of water diverted and the time such diversion occurs. These structures are constructed so that they could be moved from a channel or destroyed during periods of extreme runoff to prevent obstruction of the channel which might cause overflow and cause subsequent flood damage. Flow measuring devices may be installed at the inlet structure or in the conduit to determine the inflow quantities and check the efficiency of the project. In many projects a conduit system similar to that described above is provided to return to the main stream waters which have passed through the project.

Presented below is a detailed discussion of the seven principal methods of artificial recharge which are currently being utilized in California.

Basins

By far the most common method of artificial recharge is through the use of basins. In the basin method, water is impounded in a series of basins which are formed by a network of artificial dikes or levees generally using to full advantage the surface contours. The basins are usually arranged in series, one above the other, so that overflow from the upper basin will flow into the next lower basin.

The basin method has many advantages in operation including:

1, Basins utilize the maximum area for spreading with only the tops of the levees, which can be used for operation and maintenance, being unproductive. This is particularly important where suitable locations are scarce or land values are extremely high.

2. Irregular and gullied surfaces can be used with a minimum of preparation.

3. Silt-laden waters can be used, particularly if the upper basins are utilized for desilting and are periodically cleaned.

4. Considerable surface storage capacity is available in basins which can be used to store a portion of the water from flash floods for later slow percolation into the ground water reservoir.

5. In general, local materials can be used for construction of dikes and levees.

The objective of plans for a basin-type spreading project is to obtain the maximum ratio of the wetted area to gross area commensurate with efficient operation and maintenance. In addition, smaller basins should be designed to obtain the highest ratio of the wetted perimeter to the wetted area. However, as the basin increases in size, the effect of shape diminishes rapidly. Basin size is dependent largely on the slope of the land surface; the flatter the slope, the larger the surface area of the basin for a given height of levee.

Levees can frequently be constructed by bulldozers, using the native soils without consideration to fill slope of compaction. However, in or near urban areas where seepage may damage private property, greater attention must be given to construction details. In general, the allowance for freeboard should range from one to three feet, depending upon compaction. Roads are usually constructed on the main levees to facilitate patrolling, inspection, and operation and maintenance.

It has been found that greater flexibility of operation and maintenance can be obtained by having a minimum of two basins. This factor is important in continuous spreading projects because it permits the project to remain in operation during periods when spreading must be discontinued and basins dried for maintenance and re-establishment of infiltration rates. In projects designed to spread storm waters, multibasin operation has the advantage that the first of the series of basins can be utilized as a sedimentation pond to remove silt, which is among the more important maintenance problems. The upper pond should be large enough to substantially reduce the velocity of flow, and its inlet and outlet facilities should be so designed and located that short circuiting is prevented.

The design of any multibasin system should provide for adequate control of flow between basins. In most of the highly developed projects, the abutments of these interbasin control structures are made of concrete and the flow of water is controlled by standard size flashboards. There are many structures where abutments have been constructed of treated lumber, but under conditions of alternate wetting and drying it has been found that the wood generally deteriorates in a period of from 10 to 15 years. Other installations, such as spillways and gated culverts, have been used with great success as control structures. In all cases, proper consideration must be given to erosive action on the downstream side of the interbasin structure caused by increased velocity, and if necessary riprapping should be provided to control this erosive action.

When this type of project is utilized to spread storm flow, a return structure should be placed at the low end of the project. This structure usually consists of a weir so placed as to direct the flow back into the stream.

Modified Stream Bed

The utilization of stream channels represents an efficient and economical method of artificial recharge. Natural recharge from stream channels normally constitutes a large percentage of the natural recharge to a ground water reservoir. When the total flow in the stream channel exceeds the natural infiltration rate, the excess is lost by runoff. All efforts to increase percolation into the ground water reservoir are slanted toward conserving this excess runoff. Many agencies have constructed upstream reservoirs to regulate the erratic runoff and limit the flows to rates which do not exceed the absorptive capacity of downstream channels. Often these stream channels are simply widened, leveled, or scarified to increase the infiltration.

In other areas small check dams and dikes are frequently used to reduce velocities and spread the flow over the entire width of the channel to effect maximum infiltration. These checks may be simply temporary earth structures protected by brush, wire, vegetative cover, riprap, etc. In several streams, basin-like areas have been prepared by constructing temporary dikes of river bottom material. Temporary earth structures were constructed to quickly collapse when the flow in the river exceeds a given capacity. In some instances, this type of project has included permanent walls or weirs which have been constructed across river bottoms. However, this type of structure must be designed to take a battering from rocks, boulders, and other types of debris carried by the stream during periods of high runoff. Permanent structures are dictated by relative economics of initial cost versus maintenance and replacement expense.

Pits

There are generally two types of pits. One type is the abondoned sand and gravel pit, which is very effective for recharging the ground water body after minor modification. Unless these unplanned pits have steep sides, relatively nonsilty water is used because of the difficulty in removing the silt from the sides as well as the bottom of the pit. The other type is the steep walled, planned "basin-like pit" which is deep with relationship to its surface areal dimensions. The initial cost of both of these types of projects is generally low since all that is required is a conduit leading to the pit for the delivery of water. In both of these methods water is usually introduced into the pits by means of a pipe or open chute.

Artificial recharge by means of the planned "basin-like pits" is gaining in popularity. One of the reasons is the small initial capital cost of the project to the operating recharging agency. In many of the urbanized areas of southern California, sand and gravel operators will excavate this type of project to a given specification, and at the same time they will pay for the excavated sand and gravel. A second reason is the higher tolerance for silt than regular basins, since the silt usually settles rapidly to the bottom leaving the steep side walls relatively free for continued infiltration of water. For this type of project, provisions are usually made for rapid and economic removal of silt from the bottom of the pit.

Ditches and Furrows

The ditch and furrow method consists of a system of flat-bottomed ditches which serve to transport water and provide percolation opportunity. This method can be used to supplement a basin spreading project; it can also be successfully applied to rough stoney terrain, and to areas where slopes are too steep for basin construction. Waters with fairly high silt content can usually be satisfactorily spread, if velocities in the ditch systems are adequate to transport a large portion of the silt through the spreading system and deposit it in the main channel where it can be removed mechanically or carried out of the area during floods.

Several systems of orientation of furrows and ditches have been devised. In general, three basic types are commonly used: (1) contour type, where the ditch follows the ground contour; (2) lateral type, where water is diverted from the main canal to a series of small furrows; and (3) tree-shaped, where the water is diverted from the main canal into successively smaller canals and ditches. The design size usually corresponds to the site size. It is generally restricted to sites where land is relatively inexpensive, since the ratio of wetted area to gross area is usually very low, often averaging only about 10 per cent.

The width of a ditch may vary widely, but generally ranges from one to six feet, depending on the terrain and the velocity desired. It should be designed for velocities that will not erode the channels, but are high enough to carry the silt through the system. On very steep slopes, checks are frequently constructed for the two-fold purpose of minimizing erosion and increasing the wetted area.

In an endeavor to keep design, survey, and construction costs to a minimum, many agencies have first constructed a rough ditch by using only the simplest instrument, such as a plow. This simple facility is then improved by modification during initial operations. For this type of project, it is usually

necessary to place a collecting ditch at the lower end of the site to return the water to the stream channel.

Flooding

Flooding is a very effective and low cost method of recharge in areas where slopes are gentle and uniform, and where gullies or ridges are small. In the flooding method, water is allowed to flow over the land surface in a relatively thin sheet. Generally it is best not to disturb the native vegetation and soil cover in the flooding area in order to maintain a favorable infiltration rate.

Ditches and weir-type embankments are usually used to initially distribute the water across the upstream end of the area to be flooded. Direction of flow is controlled by a few strategically placed embankments. Peripheral dikes are usually constructed by control the water sufficiently to prevent damage to adjacent property and to return water to the stream channel.

Injection Wells

Injection of water into abandoned wells and wells specifically designed for artificial recharge has been practiced for many years with varying degrees of success. The use of injection wells is confined largely to those areas where surface spreading is not feasible due to the presence of extensive and thick impermeable clay layers overlying the principal water-bearing deposits. They may also be economically feasible in metropolitan areas where land values are too high to utilize the more common basin, flooding, and ditch and furrow methods.

Many attempts to recharge ground water through injection wells have yielded disappointing results. Difficulties encountered in maintaining adequate recharge rates have been attributed to silting, bacterial and algae growths, air entrainment, rearrangement of soil particles, and deflocculation caused by reaction of high sodium water with soil particles. However, the Los Angeles County Flood Control District in California, in cooperation with the California Department of Water Resources, has successfully operated injection wells as part of a large scale field experimental project concerning the feasibility of creating and maintaining a fresh water ridge to halt sea water intrusion in the Manhattan-Redondo Beach area in Los Angeles County. Favorable percolation rates have been maintained by chlorination and deaeration of the water supply, and by conducting a comprehensive well maintenance program.

The spacing of the injection wells depends upon the range of influence of a well, which is in turn dependent upon the amount of water to be recharged through the well, and the acceptance rate of the aquifer. The acceptance rate is a function of the aquifer permeability, hydraulic gradient, the length of casing penetrating the aquifer, and the number of casing perforations.

In general, it has been found that gravel packed wells operate more efficiently and require less maintenance than do nongravel packed wells. At Manhattan Beach, California, a 24-inch gravel packed well with an 8-inch casing was found most desirable for recharging purposes. In addition, where water is being injected under pressure, it has been found that a concrete seal should be provided on the outside of the casing at a point where it passes through the relatively impermeable cap, to prevent the upward movement of water along the outside edge of the casing.

With respect to perforations, consideration should be given to using a "Moss perforator," which makes horizontal louvered slits in the casing. This type of perforation is particularly advantageous in a predominantly sandy formation because it inhibits movement of sand from the formation into the well when injection pressure is relieved. In addition, it is suggested that the casing perforations be placed below the normal water table to lessen the chances of chemical incrustation.

A well header assembly must be provided to bring the water to the recharge well and to regulate the flow of water into the well. In general, the water to be recharged should be maintained at a relatively constant pressure, and should not be allowed to fall freely in the well, since the resulting aeration greatly affects acceptance rates. The design of this assembly will vary greatly, depending upon the purpose for which the project will be used.

It should be emphasized that if a long term project is contemplated, treatment of water is imperative. Sediment must be almost completely removed and the clear water should be treated with relatively high concentration of chlorine, calcium hypochlorite, or copper sulfate to prevent the formation of bacterial slime and algae. In addition, care should be taken to insure that no water containing a high percentage of sodium is injected, since such water will cause deflocculation of the aquifer sediments and rapid decrease in transmissibility of the aquifer. This problem is most prevalent in soils containing clay and silt, and not very important in soils made up primarily of sand and gravel.

Artificial Recharge Activities in California

Artificial replenishment of ground water reservoirs in California has been practiced for many years. As early as 1895, flood waters of San Antonio Creek in southern California were conserved by spreading on the alluvial fan at the mouth of San Antonio Canyon. The practice of artificial recharge has increased to such proportions that it is presently a major method of conservation of water in California.

The California Department of Water Resources is conducting a comprehensive investigation and inventory of all artificial recharge activities in California. The inventory indicates that artificial recharge activities are concentrated in three areas: (1) Santa Clara Valley, south of San Francisco Bay; (2) central and southern part of the San Joaquin Valley; and (3) southern California. This is readily understandable, in light of the extensive exploitation and overdevelopment in these areas, coupled with extreme variability of runoff, scarcity of suitable surface storage, and adverse water quality problems such as sea water intrusion, salt balance, and related problems.

This inventory will be presented by discussing the following: agencies conducting spreading, type and numbers of recharge projects, and quantities of water recharged. A brief presentation of costs will also be included.

Agencies Conducting Spreading Operations

As of October 1, 1958, there were 54 agencies actively practicing artificial recharge in California. The majority of the operating agencies conducting artificial recharge are public agencies such as irrigation districts, water conservation districts, and flood control districts. A summary of the type and number of agencies which had active projects in California as of

October 1, 1958, is presented in the following tabulation:

Type of Agency	Number of Agencies
Irrigation Districts	9
Water Conservation Districts	7
Flood Control Districts	7
Other Water Districts	7
Municipalities	4
Mutual Water Companies	10
Other Water Companies and Associations	6
Miscellaneous	4
TOTAL	54

Projects by Methods of Spreading

As of October 1, 1958, there are 276 active artificial recharge projects in California. All of the standard methods of placing water underground (modified stream bed, flooding, basins, pits, ditches and furrows, and injection wells) are represented in this listing. The basin method is the most commonly used method, constituting 149 projects or 54 per cent of all projects. Other methods include modified stream bed with 15 per cent, ditches and furrows with 8 per cent, pits with 7 per cent, flooding with 4 per cent, and injection wells with 12 per cent.

Quantities Recharged

The total quantity of water recharged to all ground water basins in California is not known with any degree of accuracy. However, the best estimate based on reported amounts artificially recharged during the period 1912-13 through 1957-58, through only the recharge facilities for which reports were obtained, totaled about 6.25 million acre-feet. Of this amount, about 800,000 acre-feet were imported from the Mono Basin-Owens Valley and the Colorado River, and were spread in coastal southern California. The highest annual volume reported during this period, 630,000 acre-feet, was attained in 1957-58, and this water was reported spread in 63 projects in California. Of the total amount spread in 1957-58, about 170,000 acre-feet were Colorado River water reported spread in coastal southern California.

By far the largest quantity of water has been spread by the basin method with the least quantity spread by the flooding method. Tabulated on the following page are reported quantities of water spread by various methods in the period 1957-58, and 1912-13 through 1957-58.

Method	1957-58 Acre-feet	1957-58 Per cent	1912-13 through 1957-58 Acre-feet	1912-13 through 1957-58 Per cent
Basin	367,700	58.4	2,790,900	44.7
Modified Stream Bed	185,900	29.5	2,340,500	37.5
Ditch & Furrow	59,400	9.4	1,050,100	16.8
Pit	8,500	1.3	18,400	0.3
Well	6,100	1.0	28,600	0.5
Flooding	2,400	0.4	12,500	0.2
TOTAL	630,000	100%	6,241,000	100%

Cost

The cost of artificial recharge projects varies greatly with: (1) purpose; (2) method of spreading; (3) quantity, quality and regiment of flow of water; (4) the surface and subsurface conditions; (5) the location of the artificial recharge project; and (6) the standards and requirements of the agencies. The large difference in cost of a project is exemplified by two basin type projects, both of which were constructed in about 1955. A relatively simple basin type project containing 30 acres of gross area and 26 acres of wetted area, was constructed on an alluvial fan in an unpopulated area at a total cost of less than $10,000 or considerably less than $500 per acre of wetted area of development. In contrast, a very sophisticated basin type project, containing 125 acres of gross area and 110 acres of wetted area, was constructed in a flood plain area and highly productive citrus area at a cost of about $580,000, or more than $5,000 per acre of wetted area. It is evident that there is no meaningful comparison between costs of projects in California. However, it may be of value to discuss some of the factors associated with and affecting the total cost of projects in California.

The cost of land has sometimes been a large item in the total cost of projects in California. It mainly varies with location and the time at which the purchase was effected. For example, the present worth of land at many projects located in the populated areas of southern California is over $3,000 an acre as compared to their original cost of about $200 an acre in 1930.

Also, natural resources have often been found on lands purchased for artificial recharge projects. These resources have lessened the net costs of projects. An example is the sand and gravel found on project sites located in the populated areas in coastal southern California. Sand and gravel operators have bought the material as well as removed the material under specified conditions for planned development of a basin or pit type project.

In general, lands were acquired when the need arose, but in the past, some agencies following a master plan, have bought large acreages whenever extra funds were available. In these cases, inexpensive methods of spreading, such as the ditch and furrow type, and flooding type of operation, were immediately

started to get some benefit from the land. Further improvements were made from time to time as other funds became available. Some lands were sold or even traded for more favorably located land. In some cases, legal and court fees were involved when public agencies revert to condemnation procedures.

Standards of requirements for engineering, construction, and operation and maintenance differed between agencies, which in turn, affected the cost of spreading projects. The standards and requirements were generally dictated by the type of development in and around the area, being highest in fully developed urban areas. For example, in urban areas, the cost of fencing and of patrolling the project area has added significant costs to the spreading operation.

Another item which has affected the cost of spreading projects is the type and size of appurtenances, such as installation for diversion, the conduits for conveying the water from source to the spreading project, and the installation to return the water from the spreading project to the main stem. When costs of these appurtenances were large in proportion to the development of the spreading ground itself, the cost per unit area of one project was considerably higher when compared with other projects in which cost of appurtences was not a major item.

A study was made to relate the cost of operation and maintenance to a unit amount of water spread. Operation and maintenance cost could be classified as either fixed cost or variable cost. The fixed cost portion of operation and maintenance, such as rent, utilities, taxes, and insurance, for spreading a unit volume of water varied with the amount spread, being greater when a smaller amount of water is spread. Thus, this fixed cost for spreading a unit volume of water is expected to be less during wet periods when compared with dry periods. However, the variable cost portion of operation and maintenance, such as cost of silt removal, operating personnel, and patrolling, may be great, even though a large amount of water was spread due to the inefficient use of personnel and spreading grounds. In general, high efficiency is reached whenever the spreading project is operated at design capacity. For example, about 5,000 acre-feet of local storm water and about 22,000 acre-feet of imported water were spread in a project in southern California during 1957-58. Since the release of imported water was scheduled for desired periods, and controlled to the design capacity of the spreading ground, the cost of operation and maintenance in spreading a unit volume of imported water was less than when spreading a unit volume of local storm water.

Factors Relating to Selection of Artificial Recharge Project Sites

Numerous factors enter into the selection of a potential recharge site. The engineer and geologist must carefully evaluate these factors, individually and collectively. Some of these factors include:

1. Availability and character of local and imported water supply.
2. Factors affecting infiltration rates, such as natural ground slope, surface soils, and geologic and subsurface hydrologic conditions.
3. Operation and maintenance problems.
4. Net benefits.

5. Water quality considerations.

6. Legal considerations.

However, this discussion will be confined to the first four items listed above, since the latter two items will be presented in other papers.

Availability and Character of Local and Imported Supply

The first and probably most important factor to consider is the availability of local or imported water. The design, operation, and efficiency of a recharge instaliation are influenced to a large degree by the source, nature, and regimen of the available water supply. Thus, consideration should be given to evaluation of two different types of flow: the perennial supply in which the discharge rate is relatively constant, and the more erratic supply in which the discharge rate changes rapidly.

Where a perennial supply of water is available, operation can be continuous and a high degree of efficiency can be attained. This condition can be realized where surface storage is utilized in conjunction with ground water reservoirs or where underground storage is utilized for regulation of imported water supplies.

The direct use of surface runoff may present difficult design and maintenance problems, particularly in the arid west where stream flow is erratic, and floods are violent. In order to effect any appreciable conservation of flood flow, provision must be made for handling large volumes of water in short periods of time. Loss of absorptive capacity through deposition of silt must be controlled, either by rejection of initial heavily-laden flows, temporary detention in surface storage, or maintenance of velocities adequate to carry silt through the recharge works without deleterious settlement. However, water supplies can be utilized under extremely adverse conditions by proper design of installations and adequate maintenance of facilities.

Factors Affecting Infiltration Rates

There are many factors affecting infiltration rates, most of which are difficult to separate out and determine the magnitude and effects. All the various items which make up the surface soils, and geologic and subsurface hydrologic conditions directly affect infiltration rates. The quality of the water and the procedures used in the construction, operation, and maintenance of projects also greatly affect infiltration rates, although the use of these items can be somewhat controlled to maintain desirable infiltration rates. In this presentation natural ground slope, surface soils, and geologic and subsurface hydrologic conditions will be discussed to illustrate some of the factors affecting infiltration rates. Also presented will be information on using these items as guides in obtaining an estimate of the infiltration rate for a project site.

Since infiltration rates vary with time, the long time infiltration rate was selected to study the effects of natural ground slope, surface soils, and physiographic positions. The long time infiltration rate is defined for use in this paper as that rate which exists after a period of spreading from two to four weeks, depending upon the character of the surface and sub-surface conditions. In this definition it was assumed that the rate of infiltration will not be affected by the ground water mound beneath the spreading site. Long time

infiltration rates were obtained for about 100 artificial recharge projects. The majority of these projects are located in southern California on alluvial fans and flood plains on which the soil textures are predominantly fine to stoney sands. Long time infiltration rates were also obtained for projects located in the San Joaquin Valley on low lying alluviated areas composed of soils which have predominantly silty to fine sandy loam textures. Some of the soils in the San Joaquin Valley are characterized by clay pan or iron hardpan layers which impede infiltration rates.

For this study, the principal physiographic features on which artificial recharge projects are located were selected as basis of relating long time infiltration rates to the various subsurface conditions, since a detailed determination of subsurface conditions is generally complex, time consuming, and expensive. The following are brief definitions of these principal features:

1. Alluvial Fan is a fan or cone shaped topographic feature which has been deposited by one stream or river.

2. Alluvial Fan Stream Channel is that portion of an alluvial fan which contains a recent, or active stream channel. It also includes that portion of the fan where a stream channel would have existed if the stream were not controlled by works of man.

3. Flood or Coastal Plain is the broad, relatively flat gently sloping topographic feature which has been formed and controlled by a through flowing stream or river. The Coastal Plain is further characterized by a depositional area which is essentially controlled by seal level and is terminated by the coast line.

4. Inland Alluviated Valley is mainly confined to the San Joaquin Valley which is characterized by low alluvial fans and plains.

Natural Ground Slope

The natural ground slope is somewhat related to the surface soils and the subsurface geologic conditions. In some instances it may be difficult and expensive to obtain data on surface soils and subsurface geologic conditions, especially the latter. Since it is usually easy and inexpensive to secure the natural ground slope from topographic maps, natural ground slopes may be conveniently used as a guide in obtaining an estimate of long time infiltration rate for a project site.

In California, the majority of the artificial recharge projects are located in the slope range of 10 per cent to 0.1 per cent. As shown in Plate 1, the long time infiltration rate increases with increasing slope. The line of best fit to all the points showing the relationship between long time infiltration rate in feet per day and natural ground slope in per cent, is expressed by the equation $I = 2.14 + 1.85 \text{ Log } S$. This equation shows that for a slope (S) of 10 per cent, the long time infiltration rate (I) was about 4 feet per day. Similar values for slopes of 1 per cent and 0.1 per cent are 2.1 feet per day and 0.3 feet per day respectively. Equation of the line which describes the upper limit of this relationship is $I = 4.39 + 3.26 \text{ Log } S$. Equation of the line describing the lower limit of this relationship is $I = 0.67 + 0.78 \text{ Log } S$.

Surface Soils

Soil types are an important factor in the establishment of initial infiltration rates. In general, the coarser the texture of the soil, the higher are the initial and sustained infiltration rate. There are other chemical, physical,

and organic properties of a soil which affect infiltration rates. These properties include:

1. Permeability
2. Claypan and iron or lime hardpan development in the soil profile.
3. Depth of soil profile.
4. Organic matter.
5. Type of crop culture.
6. Degree of compaction in construction, operation, and maintenance of the grounds.

Soil type may be inexpensively identified by using existing soil maps. Where soil maps are not available, a quick reconnaissance can be accomplished by strategic placement of several hand auger holes to determine the soil profile. In addition to the natural ground slope, soil type may be conveniently used as a supplemental guide in obtaining an estimate of infiltration rate for a project site.

Existing soil maps were utilized for determining the major soil types at each recharge project in California. The predominant soils are the Tujunga, Hanford, and Yolo series, and the loamy texture soil types existing in the San Joaquin Valley. All soil types found at spreading projects, with the exception of the San Joaquin Valley soils, are permeable, have good surface and subsurface drainage, are generally lacking a claypan or hardpan in the soil profile, and are low in organic matter.

As shown on Plate 1, the long time infiltration rate for a given soil series generally increases with increasing slope until a maximum value is reached. Then the long time infiltration rate decreases with increasing natural ground slope. In general, the highest infiltration rates occur in those recharge projects underlain by the soils of the Tujunga series. Maximum infiltration rate of 4 feet per day on this soil appears to occur with a natural ground slope of 0.9 per cent. This is probably accounted for by the uniform grain size of the soil near the 0.9 per cent slope in which the ratio of voids to total mass of this type of soil is at a maximum. A similar relationship is noted in the Yolo series, with a maximum infiltration rate occurring at 0.75 per cent natural ground slope. The fine loamy soils in the San Joaquin Valley in the natural ground slopes of about 0.1 to 0.3 per cent do not show this relationship, and the average long-time infiltration rate appears to be about 0.5 feet per day for this range of slopes.

Sufficient data were available to obtain a family of curves showing the relationship between long-time infiltration rates and soils of the Hanford series found on alluvial fans, in recent stream channels on alluvial fans, and on flood plains. In general, for a given natural ground slope the long time infiltration rate is relatively higher for projects located in recent stream channels on alluvial fans than for projects not located in recent stream channels but on alluvial fans. The long time infiltration rates of projects located on flood plains are relatively high. This may be due to the high degree of maintenance received by projects located on the flood plains.

Geologic and Subsurface Hydrologic Conditions

After the applied recharge water has passed through the soil zone, then the geologic and subsurface hydrologic conditions control the sustained infiltration

rates. In order to have a complete picture of the subsurface conditions, the following geologic and hydrologic characteristics should be thoroughly investigated to determine the total usable storage capacity, and the rate of movement of water from the spreading grounds to the areas of ground water draft, which will control the sustained infiltration rate:

1. Physical character and permeability of subsurface deposits, and depth to ground water.
2. Specific yield, thickness of the deposits, and position and allowable fluctuation of the water table.
3. Transmissibility, hydraulic gradients of the water table and pattern of pumping.
4. Structural and lithologic barriers to both vertical and lateral movement of ground water.

A detailed determination of subsurface conditions is generally time consuming and expensive. However, physiographic positions which are generally related to many of these subsurface conditions can be easily and inexpensively determined. In addition to natural ground slope and soil type, physiographic position may be conveniently used as another supplemental guide in obtaining an estimate of long time infiltration rate for a project site.

Artificial recharge projects in California are generally located on four physiographic positions which have been described earlier: (1) alluvial fan; (2) alluvial fan--recent stream channel; (3) low alluvial fan--San Joaquin Valley; and (4) flood or coastal plain. As shown on Plate 2, the long time infiltration rates of projects located in a given physiographic position generally increases with increasing natural ground slope until a maximum value is reached. Then it decreases with increasing natural ground slope. The highest long time infiltration rates appear to occur in the alluvial fan--recent stream channel at about 3.5 per cent natural ground slope. As the slope increases above 3.5 per cent, the long time infiltration rate decreases. A similar relationship is found in the alluvial fans where the maximum infiltration rates occur at about 4.5 per cent natural ground slope. Infiltration rates for the flood or coastal plain areas increases with increasing slope, and the maximum rate appears to occur at about 0.85 per cent natural ground slope. Average long time infiltration rates in the San Joaquin Valley remain relatively constant at about 0.5 feet per day for natural ground slopes ranging between 0.1 and 0.3 per cent.

A study was made to determine the relationship between long time infiltration rates and specific yield values of materials underlying the spreading grounds. The specific yield values were based on interpretation of well logs. Although long time infiltration rates were expected to increase with increasing values of specific yield, no relationship was found. This may have resulted from the large variation in the interpretation of subsurface material by well drillers.

Operation and Maintenance

It is axiomatic that any project should be operated and maintained to obtain the maximum benefits for which the project was specifically designed. The details involved in the operation and maintenance of a specific artificial recharge project vary greatly with the purpose, the method employed, the

character of the water, and the location of the project. However, there are a number of basic problems which can be anticipated. These problems not only affect infiltration rates, but also affect such important conditions as public health and safety. Some of these problems, their manifestations, and corrective actions which may be taken are set forth in Table 1.

In order for the project operator to do an efficient job, he must know the purpose of his operation, and the details and capacities of the physical features of the project. In addition, he should know the actions to be initiated in case of emergencies or failures. It has been found that specific operating instructions have been extremely helpful, particularly when the project is large and complex, and when spreading is periodic as in the conservation of storm runoff. Such an instruction sheet should include among other matters the purpose of the project, a clear definition of the duties and responsibilities of the operator, instructions relating to items to be measured and operation of measuring devices, and instructions on the use of special equipment.

In an area where spreading is contemplated on a continuous basis, personnel are usually assigned to operate the grounds on a more or less permanent basis, and operation is usually relatively routine. Under these conditions, maintenance of a project is closely associated with operation; and schedules must include an occasional shutdown period of short duration to permit proper maintenance of equipment and structures and to sustain infiltration rates. For this type of operation it may be desirable to provide some type of treatment of water prior to spreading. The number and duration of periods of shutdown for maintenance should be scheduled to obtain maximum infiltration capacity from the spreading area.

In contrast, a spreading area utilizing uncontrolled storm waters usually encounters more operational problems than projects utilizing controlled flows. The personnel who operate the ground are not normally required to attend the grounds until runoff occurs. Maintenance of spreading grounds used to infiltrate uncontrolled storm waters need not be closely timed to operations. Normally these grounds are out of operation during a large portion of the year because of lack of runoff, and maintenance work necessary to the project can be accomplished during these periods.

Silting of spreading grounds is a common operation and maintenance problem. At the time that runoff occurs the silt content of the stream should be determined. When the silt content is reduced to what is estimated by experience to be an allowable concentration, diversion can be initiated. The allowable silt content in the water diverted for spreading varies from project to project with the method of spreading, vegetative cover, surface soil, and relative cost of removing the silt from the spreading grounds. The allowable concentration of silt at each project is usually determined by experience, and is usually less than 1,000 ppm. Generally 10,000 ppm is the maximum limit. One agency does not permit the concentration of suspended and precipitable solids to exceed 20 ppm in water diverted for spreading.

In diverting to spreading grounds of uncontrolled flood water, care must be taken to fill the spreading grounds slowly to prevent breakdown of uncompacted dikes and other earthfills. In addition, constant patrol must be maintained to observe sloughing, leaking, erosion, or other signs of structural failure.

Evaluation of Net Benefits

Consideration of any plan to artificially replenish a ground water body

TABLE 1

OPERATION AND MAINTENANCE PROBLEMS

Problem	Manifestation	Corrective Actions to be Considered
Silt	Lodging of particles within interstices of soil near the surface area, reducing the infiltration rate.	(1) Desilt in retention reservoir and/or in uppermost series of basins. Flocculating agent such as "Separan" has been used with success. (2) Bypass water until concentration of silt will not be detrimental, with concentration depending upon soil condition. Ditches and furrows generally can accept waters containing higher concentrations of silt if sufficient velocity is maintained through the project to carry silt back to the main canal. (3) Scrape, harrow, and/or disc after proper drying. Period of drying usually ranges from one to seven days depending upon soil and weather conditions. (4) Remove silt after drying. Silt may be used to build up levees of basins or bridges of ditches or furrows. (5) Sustain vegetative growth. (6) Sluice the silt out of ditches and furrows, and from channels, with due regard to erosion problems. (7) Pump injection well to loosen silt from interstices and remove silt from the well.
Weeds	Increases percolation rate and shortens drying period required for working an area or removing silt from the basin. There is a disadvantage in that vegetative growth may be a fire hazard.	(1) Control by chemical means and/or remove when weeds become a fire hazard, especially around structures. Consider use of hand labor instead of mechanical means in order to maintain infiltration rates. However, if possible, leave vegetation undisturbed in wetted area. (2) Prolonged deep submergence will kill vegetation. (3) The control of weeds is generally not considered a problem in the operation of pits and shafts, or injection wells.
Rodents	Leaks and failures of dikes and levees. Public nuisance near urban area.	(1) Set out poison about twice a year. (2) Use of traps.
Public health and safety	Rodents and mosquito problem and possible injury to individuals. Potential problems of injury is greatest when depth of water is large in basins and pits.	(1) Enclose area with fence and gates with locks. (2) Patrol area with particular attention to children and structural failures, before and during operation, especially near inhabited area. (3) Vector control by use of mosquito fish, chemicals, and/or drying. (4) Rodent control by poisoning or traps. (5) Proper posting of signs when using chemical which is poisonous.

IR 4

TABLE 1

OPERATION AND MAINTENANCE PROBLEMS
(continued)

Problem	Manifestation	Corrective Actions to be Considered
Maintaining of percolation rates	Reduction of percolation rates will decrease efficiency of system, increasing the unit cost of the amount of water actually recharged.	(1) Proper treatment of water. Desilt water to concentration desired. Use chlorine or copper sulfate for control of bacterial slime and algae. Use of chemicals to reduce the possibility of chemical incrustation, which is usually deposition of calcium carbonate. (2) Schedule intermittent drying periods to prevent problems due to swelling of soil particles. Permit growth of vegetation to decrease the drying period by removing the water in the root zone and loosening the soil. Studies have shown that bermuda grass has been successfully used to maintain rates, even under prolonged periods of deep submergence. (3) Prevent aeration of water, especially when operating recharged wells, pits, and shafts. (4) Increase head of water generally by increasing depth of water. (5) Use hand labor whenever possible to decrease the possibility of using heavy equipment which will cause surface compaction especially when soil is wet. (6) Scrape, harrow, and/or disc after proper drying. (7) Remove silt, chemical incrustation, and/or any material decreasing infiltration rates after proper drying period. (8) Maintain the design velocity to reduce silting to a minimum in use of ditches and furrows. (9) Recondition injection wells by use of dry ice, hydrochloric acid, and/or sulfuric acid. (10) Prevent freezing of water during winter by continuous spreading. (11) Check the possibility of base exchange reactions. (12) Soil can be reconditioned by using organic material such as cotton gin trash, or chemical agents, such as krilium.
Maintenance to diversion structures	Breakdown of spreading operations.	(1) Systematic and routine maintenance check as well as patrolling when in operation. Attention should be given to wooden structures since they deteriorate faster due to frequent wetting and drying cycles. Also attention should be given to settlement of structures thus changing flow condition. (2) Attention should be given to undercutting of structure particularly on the downstream end which preventive maintenance primarily in the form of riprapping. (3) Sluicing of channel to remove silt and debris which have accumulated near and at diversion structure.

presupposes the desirability or necessity of augmenting the existing water supply or the use of the ground water body for storage and distribution of local and imported supplies. An evaluation of net benefits is necessary to enable the engineer to decide whether or not to conduct artificial recharge operations. An evaluation of net benefits of a surface water system can be measured directly as the amount of revenue obtained as a result of the project. However, when dealing with artificial replenishment, the amount of benefits obtained may not be easily related to tangible form. In many cases, the organization conducting the operation will realize, at best, only partial direct benefit. Furthermore, the problem may be complicated by factors of ground water hydrology and quality which may be exceedingly difficult to accurately evaluate in monetary terms.

In general, the benefits to be derived through artificial replenishment of ground water basins may be broadly grouped into two categories: (1) relief of overdraft on the ground water basin; and (2) use of ground water basins as reservoirs and distribution systems.

Relief of Overdraft

There are certain calculable benefits which are immediately apparent where artificial replenishment is conducted for the purpose of relieving overdraft on a ground water basin. These include: a possible decrease of energy charges for pumping as a result of a reduction of pumping lifts; the prevention of possible capital expenditures for deepening of wells and the lowering of pumps; and the prevention of possible premature abandonment of wells.

Benefits which would be difficult to calculate can be derived where replenishment of an overdrawn basin can prevent sea water intrusion, the release of deep seated connate brines, or the possible dewatering of the basin or portions thereof; any one of which could result in the partial or complete failure of the underground basin to yield a continued supply of water. Some measure of this benefit might be derived from a determination of the cost of replacing the lost facility with an equivalent surface system. However, the value of the ground water basin as an emergency supply is inestimable.

To obtain maximum benefits from artificial recharge however, the ground water basin must have the necessary geologic and hydrologic characteristics to permit the infiltration and transmission of the water required to relieve the overdraft. If these characteristics are not adequate for the purpose, some combination of ground water basin development and surface water distribution system must be developed. In this case, the net benefit of recharge would be evaluated as a difference between the cost of a surface system designed to completely supply the area under consideration with water from an available water supply, and comparable costs of a system to supplement the ground water supply with water from the same available water supply.

Use of Ground Water Basin as Reservoir and Distribution System

The benefits of utilizing a ground water basin as a reservoir for the storage and regulation of surface supplies can be measured by the saving in cost of equivalent surface storage reservoirs and appurtenant facilities. This saving will be particularly great at locations where there are few, if any, natural reservoir sites and surface regulating facilities may be exceedingly expensive.

In order to derive benefit from the use of a ground water basin as a reservoir, geologic and hydrologic conditions must be favorable for the desired storage and regulation. Two factors must be considered: (1) availability and development of ground water storage capacity to meet projected requirements for regulation of both local water and imported supplies; and (2) sufficient transmissibility in the aquifers to permit the movement of the spread water from the point of replenishment to the point of extraction. The usable capacity of the ground water reservoir can be developed by planned extractions of the ground water during periods of deficient supply, and subsequent replenishment during periods of surplus surface supply in much the same manner as a surface reservoir would be operated.

One of the largest benefits which can be derived is the saving in cost of developing equivalent usable capacity in a surface storage reservoir. A second large but calculable benefit when using the aquifer as a distribution system is the savings derived in terms of the difference of cost of a surface distribution system to supply part or all of the demands with due regards to peak requirements. An additional benefit of the utilization of a ground water basin is the saving in water which would be lost by evaporation from a surface reservoir. This could be computed as the cost of the water saved. An aspect which is very difficult to evaluate is the high degree of protection from contamination that is characteristic of ground water. This immunity, together with elimination from danger of destruction of reservoir structures and the wide dispersion of outlet facilities that can be attained, makes the ground water basin of value as an emergency supply, particularly in the event of nuclear warfare.

One of the more important negative benefits is the excess loss of water due to consumptive use of water by phreatophytes in areas where high ground water tables would exist. Encroachment on storage required to conserve local runoff in order to regulate imported supplies must be considered a negative benefit.

Importance of Artificial Recharge Operations to Water Conservation Activities in California

The California Department of Water Resources has developed a comprehensive master plan for the control, protection, conservation, distribution, and utilization of the waters of California. This plan, known as The California Water Plan, has been formulated to meet the present and estimated future needs of the State to the maximum feasible extent. The role of artificial recharge plays an important part in this over-all plan.

Incorporated in this plan is a system of major facilities to redistribute excess waters from northern areas of surplus to areas of deficiency throughout the State. It is estimated that the total regulatory and conservation storage required under the plan exceeds 100 million acre-feet, more than 80 million acre-feet in excess of existing surface storage facilities. In the Central Valley alone, 40 million acre-feet of additional storage are required, far beyond the capabilities of remaining suitable surface sites. The solution to this problem lies in large scale utilization of underground reservoirs which fortunately are readily available. This plan presently contemplates a combination of 22 million acre-feet of surface storage in a series of foothill reservoirs and 31 million acre-feet of underground storage for meeting ultimate

water requirements in the Central Valley. The operation of these surface and ground water reservoirs would be coordinated to achieve optimum conservation. This would be accomplished by drawing on ground waters during dry periods, thus creating storage space in underground reservoirs to be utilized for storing excess runoff during ensuing wet years. Lands would be supplied alternatively from surface or ground water storage, as dictated by prevailing conditions. Replenishment of ground water reservoirs would be accomplished by artificially recharging local and imported waters through facilities provided for this purpose, by percolation of normal excesses of applied irrigation water and of precipitation during wetter years, and by seepage of water from surface distribution canals, most of which would be unlined to increase percolation opportunity. Although this proposed "conjunctive operation" of surface and ground water reservoirs is unprecedented in scope and magnitude, there are actually no new principles involved, and there is every confidence that it constitutes the most feasible method for fully developing the water resources of the State. It is recognized, however, that many legal, financial, and operational problems must be solved before the plan can be implemented. Utilization of both surface and ground water resources must be coordinated on a regional or basin wide basis; existing water rights must be established and recognized; and costs must be apportioned on an equitable basis. However, under the urgencies generated by the tremendous growth of the State's economy, solutions will be found for all these problems, and the practicability of "conjunctive operation" of surface and ground water storage on a grand scale will be fully demonstrated.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the many individuals who have contributed to the information presented herein. Special appreciation is due Mr. Max Bookman, District Engineer, Mr. Lucian Meyers, Principal Hydraulic Engineer, Donald H. McKillop, Senior Hydraulic Engineer, and Robert G. Thomas, Senior Engineering Geologist, who reviewed and commented upon the original draft of this paper. Mention is also made of the helpful assistance of Mr. Sanford L. Werner, Assistant Engineering Geologist, in the preparation of this paper.

BIBLIOGRAPHY

1. American Society of Civil Engineers, Committee on Hydrology of the Hydraulics Division, "Hydrology Handbook." Manual of Engineering Practice. No. 28, January 17, 1949.
2. Anonymous. "Pouring It Back." Industrial and Engineering Chemistry, Vol. 44. No. 3, Page 18A and 20A. March, 1952.
3. Banks. H. O., Richter, R. C., Coe, J. J., McPartland, J. W., and Kretsinger, R. "Artificial Recharge in California." Paper Presented Before the Hydraulic Division, American Society of Civil Engineers, Austin Texas. September 8, 1954.

4. Barksdale, H. C. and Debuchananne, G. D. "Artificial Recharge of Productive Ground Water Aquifers in New Jersey." Economic Geology. Vol. 41. No. 7. 1946.

5. Bauman, P. "Ground Water Movement Controlled Through Spreading." American Society of Civil Engineers Proceedings. Separate No. 86. August, 1951. American Society of Civil Engineers Transactions. Vol. 117. Paper No. 2525. 1952.

6. Bennison, E. W. "Replenishment of Ground Water Supplies." American Water Works Association Journal. Vol. 41. No. 2. February, 1949.

7. Bliss, E. S. and Johnson, C. E. "Some Factors Involved in Ground Water Replenishment." American Geophysical Union Transactions. Vol. 33. No. 4. August, 1952.

8. Boswell, P. G. H. "Artificial Replenishment of Underground Water Resources in the London Basin." Water and Water Engineering. Vol. 58. No. 700. 1954.

9. Brashears, M. L. "Artificial Recharge of Ground Water on Long Island, New York." Economic Geology. Vol. 41. No. 5. 1946.

10. California State Department of Public Works, Division of Water Resources. "Progress Reports on Investigations for Prevention of Sea-Water Intrusion Under Provisions of Chapter 1500, Statutes of 1951." 1952 to April, 1954. Unpublished.

11. California State Department of Public Works, Division of Water Resources. "Second Progress Report of the California Legislature and the Regional Water Pollution Control Board on Reclamation of Water from Sewage and Industrial Wastes." Water Quality Investigation Report. April, 1954.

12. California State Department of Public Works, Division of Water Resources. "Proposed Investigational Work for Control and Prevention of Sea-Water Intrusion into Ground Water Basins." August, 1951.

13. California State Department of Public Works, Division of Water Resources. "Progress Reports on Investigation for Prevention of Sea-Water Intrusion Under Provisions of Chapter 1500, Statutes of 1951." Unpublished.

14. California State Department of Water Resources. "Office Report on Geologic Considerations in Artificial Recharge of Ground Water Reservoirs in California." May, 1957.

15. California State Department of Water Resources. "Office Report on an Abstract of Literature and Bibliography Pertaining to Percolation Rates in Artificial Recharge Projects in California." August, 1957.

16. California State Department of Water Resources, Division of Resources Planning. "Artificial Recharge in California." In preparation.

17. California State Department of Water Resources. "Sea-Water Intrusion in California." Bulletin No. 63. November, 1958. Appendix B. March, 1957.

18. California State Water Pollution Control Board. Publication No. 11. "Report on the Investigation of Travel of Pollution." 1954.

19. Cederstrom, D. J. and Trainer, F. W. "Artificial Recharge of Water-Bearing Beds in Anchorage." Paper Presented at the Alaska Science Conference, Anchorage, Alaska. September 8, 1954.

20. Conkling, H. "Utilization of Ground Water Storage in Stream System Development." American Society of Civil Engineers Proceedings. Vol. 71. No. 1. January, 1945. American Society of Civil Engineers Transactions. Vol. 111. Paper No. 2272. 1946.

21. Ferris, J. G. "Water Spreading and Recharge Wells." Indiana Department of Conservation, Division of Water Resources. Water Conservation Conference Proceedings. 1950.

22. Guyton, W. F. "Depleted Wells at Louisville Recharged with City Water." Water Works Engineering. Vol. 98. No. 1. 1945.

23. Guyton, W. F. "Artificial Recharge of Glacial Sand and Gravel with Filtered River Water at Louisville, Kentucky." Economic Geology. Vol. 41. No. 6. 1946.

24. Hall, W. A. "Some Theoretical Aspects of Water Spreading on Agricultural Soils." University of California, Davis, California. Mimeographed Report. 1955.

25. Hall, W. A. "Perched Water Tables Under an Artificial Ground Water Recharge System." Transactions of the American Geophysical Union. Vol. 38. No. 3. June, 1957.

26. Harrell, M. A. "Artificial Ground Water Recharge, A Review of Investigations and Experience." United States Department of the Interior, Geological Survey. Unpublished Report. 1935.

27. High Plains Underground Water Conservation District monthly publications. "The Cross Section."

28. Illinois State Water Survey Division mimeographed report for each year of operation.

29. Jansa, V. "Artificial Replenishment of Underground Water." International Water Supply Association. Second Congress. Paris, France. 1952.

30. Jennings, J. C. "Disposal of Waste Cooling Water." American Water Works Association Journal. Vol. 42. No. 6. June, 1950.

31. Kazmann, R. G. "Ground Water Storage and Recharge." Public Works. Vol. 81. No. 2. 1950.

32. Kent, L. E. "Artificial Recharge of Ground Water in the Union of South Africa." Union of South Africa. Geological Survey. 1954.

33. Klaer, F. H., Guyton, W. F., and Todd, D. K. "A Preliminary List of References Pertaining to Artificial Recharge of Ground Water in the United States." United States Department of the Interior, Geological Survey. Mimeographed Report.

34. Kramsky, M. "Utilization and Artificial Replenishment of Ground Water Reservoirs." University of Southern California. Masters Thesis. June, 1952.

35. Laverty, F. B. "Ground Water Recharge." American Water Works Association Journal. Vol. 44. No. 8. August, 1952.

36. Laverty, F. B. "Recharging Ground Water With Reclaimed Sewage Effluent." Civil Engineering, Vol. 28, No. 8. August, 1958.

37. Leggette, R. M. and Brashears, M. L., Jr. "Ground Water for Air-Conditioning on Long Island, New York." American Geophysical Union Transactions. Vol. 19. Part 1. 1938.

38. Los Angeles County Flood Control District. "Report on Tests for Creation of Fresh Water Barriers to Prevent Salinity Intrusion Performed in West Coastal Basin, Los Angeles County, California." March 10, 1951.

39. Los Angeles County Flood Control District. "Progress Reports, West Coast Basin Barrier Test." 1950 to November, 1953. Unpublished.

40. Lowdermilk, W. C. "Some Problems of Hydrology and Geology in Artificial Recharge of Underground Aquifers." United Nations Educational, Scientific, and Cultural Organization. Proceedings of the Ankara Symposium of Arid Zone Hydrology. Paris, France. 1953.

41. Martin, H. "Artificial Recharge of Ground Water in Southwest Africa." Union of South Africa. Geological Survey. 1954.

42. McGuinness, C. L. "Recharge and Depletion of Ground Water Supplies." American Society of Civil Engineers Transactions. Vol. 112. 1947.

43. Meinzer, O. E. "General Principles of Artificial Ground Water Recharge." Economic Geology. Vol. 41. No. 3. 1946.

44. Mitchelson, A. T. "Spreading Water for Recharge." Soil Conservation Vol. 15. No. 3. 1949.

45. Muckel, D. C. "Research in Water Spreading." American Society of Civil Engineers Proceedings. Vol. 77. Separate No. 111. December, 1951. American Society of Civil Engineers Transactions. Vol. 118. 1953.

46. Rawn, A. M. "Blending of Sewage Effluent with Natural Waters Permits Reuse." Civil Engineering. Vol. 20. 1950.

47. Remson, I., Randolph, J. R., and Barksdale, H. C. "Zone of Aeration and Its Relationship to Ground Water Recharge." Journal American Water Works Association. Vol. 51. No. 3. March, 1959.

48. Sayre, A. N. and Stringfield, V. T. "Artificial Recharge of Ground Water Reservoirs." American Water Works Association Journal. Vol. 40. No. 11. November, 1948.

49. Schiff, L. "The Status of Water Spreading for Ground Water Replenishment." American Geophysical Union Transactions. Vol. 36. No. 6. December, 1955.

50. Schiff, L. and Johnson, C. E. "Some Methods of Alleviating Surface Clogging in Spreading Water for Recharge." Presented at Pacific Southwest Regional Meeting of the American Geophysical Union, Sacramento, California, February 15, 1957.

51. Schiff, L. "The Use of Filters to Maintain High Infiltration Rates in Aquifers for Ground Water Recharge." Presented at the Eleventh General Assembly of I.U.G.G., Toronto, Canada, September 3-14, 1957.

52. Shuval, H. "Did Ancient Engineers Know Best?" Engineering News Record. April 17, 1958.

53. Silitch, E. W. "The Place of Ranney Collectors in the Water Supply Industry." New Hampshire Water Works Association Journal. October, 1948.

54. Simpson, T. R. "Utilization of Ground Water in California." American Society of Civil Engineers Proceedings. Separate No. 102. December, 1951. American Society of Civil Engineers Transactions. Vol. 117. Paper No. 2522. 1952.

55. Stone, R. and Garber, W. F. "Sewage Reclamation by Spreading Basin Infiltration." American Society of Civil Engineers Proceedings. Vol. 77. Separate No. 87. September, 1951. American Society of Civil Engineers Transactions. Vol. 117. Paper No. 2530. 1952.

56. Sundstrom, R. V. and Hood, J. W. "Results of Artificial Recharge of the Ground Water Reservoir at El Paso, Texas." Texas Board of Water Engineers. Bulletin 5206. 1952.

57. Suter, R. "Specifications for Diffusion Wells." City of New York Division of Water Power and Control. Albany. 1945.

58. Task Group E-4B on Artificial Ground Water Recharge. "Artificial Ground Water Recharge." American Water Works Association Journal. Vol. 44. No. 3. 1952.

59. Texas State Board of Water Engineers. "Results of Artificial Recharge of the Ground Water Reservoirs at El Paso, Texas." Bulletin 5206. July, 1952.

60. Texas State Board of Water Engineers. "Artificial Recharge Experiment at MacDonald Well Field, Amarillo, Texas.

61. Thomas, H. E. "Artificial Recharge of Ground Water by the City of Bountiful, Utah." Transactions American Geophysical Union. Vol. 30. No. 4. 1949.

62. United States Congress, Interior and Insular Affairs Committee, House of Representatives. "Ground Water Regions of the United States - Their Storage Facilities." 1952.

63. United States Department of Agriculture. "Spreading Water for Storage Underground." Technical Bulletin No. 578. December, 1937.

64. United States Department of Agriculture, Agricultural Research Service, Soil and Water Conservation Branch. "Annual Report 1955. Water Spreading, Bakersfield, California." March 1, 1956.

65. United States Department of Agriculture, Agricultural Research Service, Soil and Water Conservation Research Division. "Replenishment of Ground Water Supplies by Artificial Means." Technical Bulletin No. 1195. February, 1959.

66.

67.

68.

69.

70.

71.

72.

73.

74.

75.

66. United States Department of the Interior, Geological Survey, Ground Water Branch. "Artificial Recharge of Ground Water an Annotated Bibliography, Through 1954." Open-file Report. 1957.

67. University of Arkansas, Department of Agricultural Engineering, Agricultural Experiment Station. "Ground Water Recharge by Means of Wells." September, 1954.

68. University of California at Berkeley. "Final Report on Investigation of Travel of Pollution." Sanitary Engineering Research Project. 1954.

69. University of California, Sanitary Engineering Research Laboratory. "An Investigation of Sewage Spreading on Five California's Soils." June, 1955.

70. University of California, Sanitary Engineering Research Project. "Present Economic and Technical Status of Water Reclamation from Sewage and Industrial Wastes." Technical Bulletin No. 4. March, 1951.

71. University of California, Sanitary Engineering Research Project. "Summary Report Pertaining to Basic Parameter of Sea-Water Intrusion and the Hydraulics of Injection Wells." May 25, 1953.

72. University of California, Sanitary Engineering Research Laboratory. "Final Report on Sea-Water Intrusion." September, 1953.

73. University of California, Department of Engineering. "Progress Report - Study of Problems Associated With Ground Water Recharge Barrier to Prevent Chloride Infiltration." December, 1952.

74. Van der Goot, H. A. and Hertel, R. M. "A Report Summarizing Progress on Hyperion Waste Water Reclamation Research Project." Los Angeles Flood Control District. March 30, 1956.

75. Volk, K. G. "Maintenance and Operating Problems of Water Spreading Grounds in Southern California." American Geophysical Union Transactions. Vol. 15. Part II. 1934.

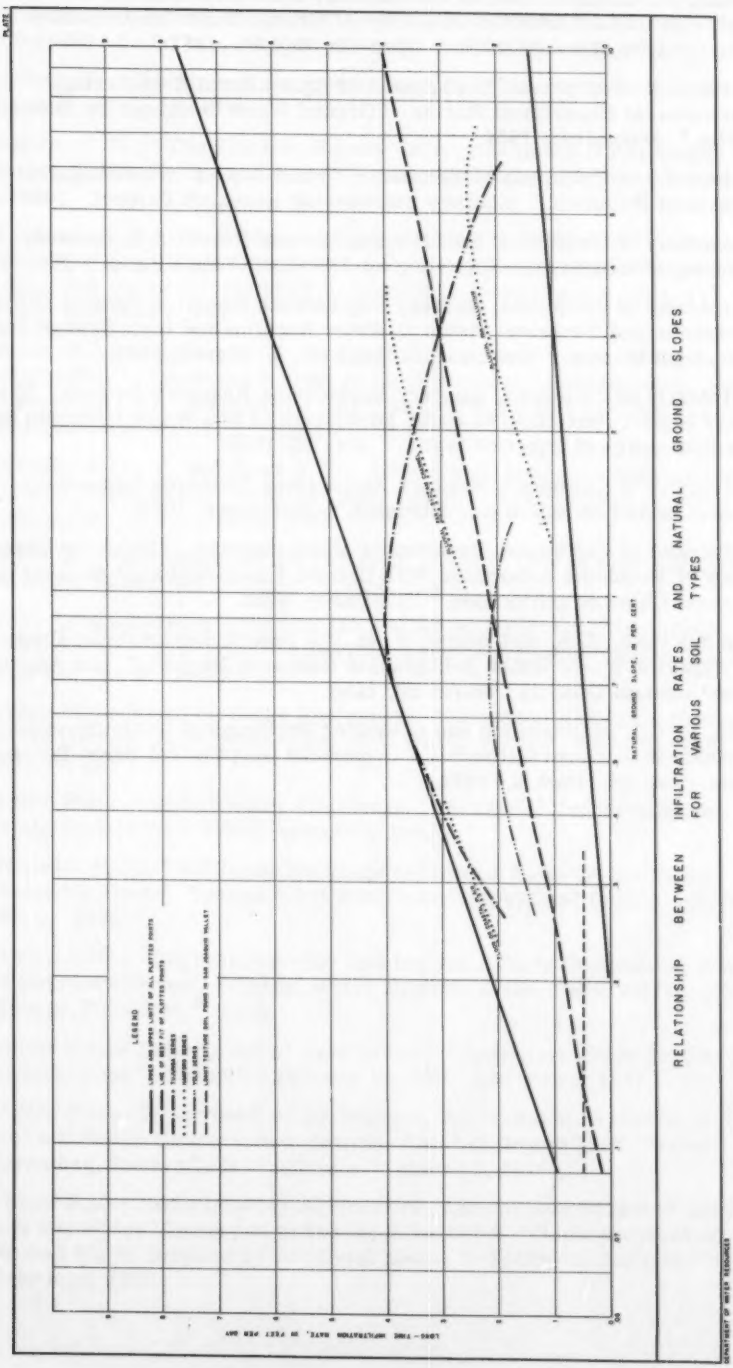


PLATE 1
LEGEND
LOWER AND UPPER LIMITS OF ALL PLOTTED POINTS
LINE OF BEST FIT OF PLOTTED POINTS
TUJUNGA SERIES
HANFORD SERIES
YOLO SERIES
LONG TEST FOR SOIL FROM IN SAN JOAQUIN VALLEY
LONG-TIME INFILTRATION RATE, IN FEET PER DAY
NATURAL GROUND SLOPE, IN PER CENT
RELATIONSHIP BETWEEN INFILTRATION RATES AND NATURAL GROUND SLOPES FOR VARIOUS SOIL TYPES
DEPARTMENT OF WATER RESOURCES

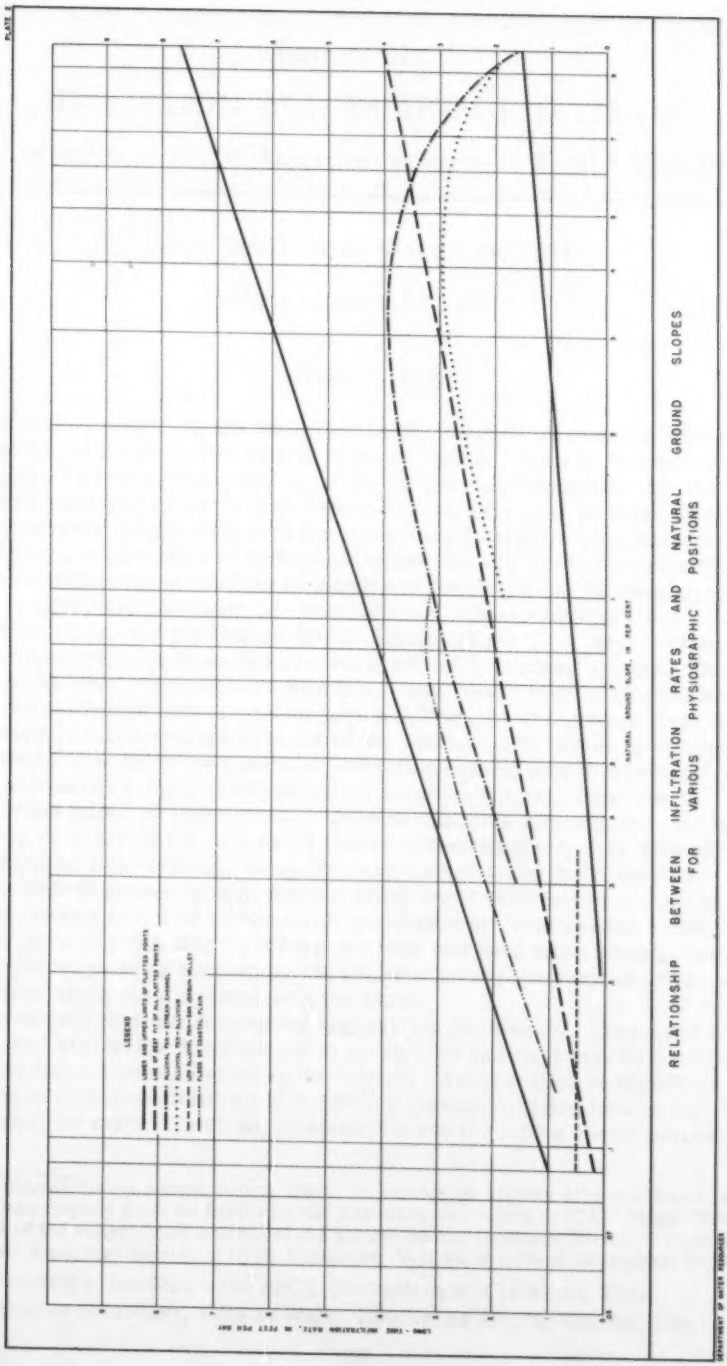
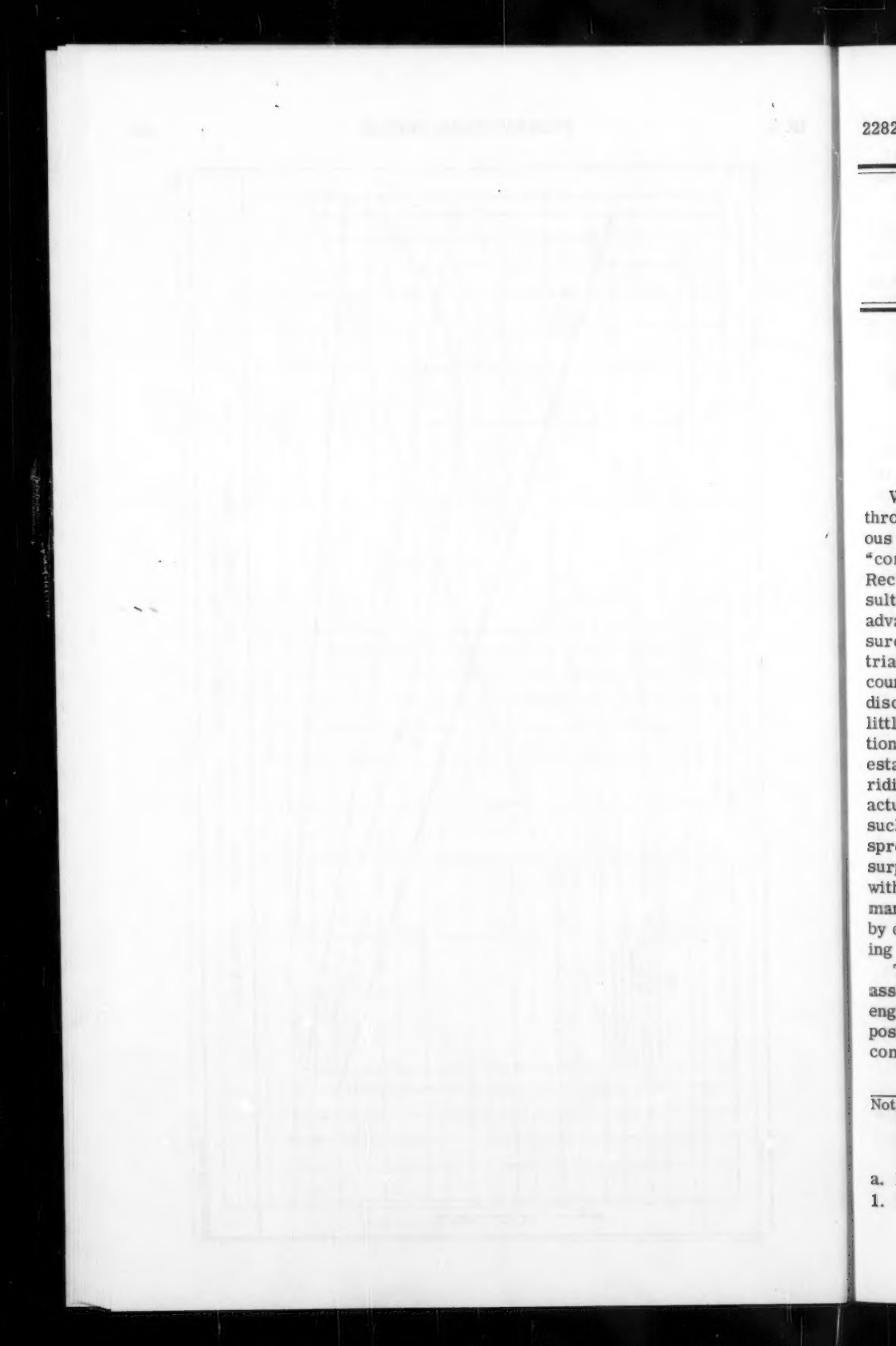


PLATE 2
LEGEND
LOWER END (UPPER LIMIT OF PLOTTED POINTS)
LINE OF BEST FIT OF ALL PLOTTED POINTS
ILLUVIAL PEAT - ESTUARY CHANNEL
ILLUVIAL PEAT - ALLUVIUM
SAN ELIJO, PEAT - SAN DIEGUITO VALLEY
FLOOR OF COASTAL PLAIN
LONG - TERM INFILTRATION RATE, IN FEET PER DAY
NATURAL GROUND SLOPE, IN PER CENT
RELATIONSHIP BETWEEN INFILTRATION RATES AND NATURAL GROUND SLOPES FOR VARIOUS PHYSIOGRAPHIC POSITIONS
DEPARTMENT OF WATER RESOURCES



Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

THIS PROBLEM OF WATER RIGHTS[a]

Robert L. Smith,[1] M. ASCE

INTRODUCTION

Within the present decade there has been a marked increase in interest throughout the nation in the subject of water rights. Prior to this time, serious consideration of "statutory water rights law" as contrasted with the "common law" was more or less confined to the seventeen western states. Recent interest in this subject in the more humid parts of the country results from a combination of factors including, but not limited to, significant advancements in the technology of supplemental irrigation, increasing pressures in every area of water use ranging from outdoor recreation to industrial processing, and the severe drouth history of the 50's. Opinions and counter opinions have been and are being voiced by various groups. These discussions have generally assumed that consumptive uses or diversions have little or insufficient security under common law; but at the same time, questions have also been raised in some of the common-law states as to whether established uses have any practical protection against new diversions. Overriding the entire subject is the sensitive situation wherein most use is actually exercised by individuals or private interests although the effects of such use, because of the migratory nature of the resource, may have widespread public implications. In most every common-law state, there are surplus waters presently undeveloped which could be diverted and put to use without ruinous effect on either established uses or other needed future demands. How to pluck this fruit from the tree and keep from being poisoned by over-indulgence is essentially the problem facing the various policy making bodies which must wrestle with the issue.

The subject is of concern to the engineering profession. Engineers are associated with water development of every kind and so it may be said the engineer has a vested interest in the subject. Accordingly, he should be in a position to contribute usefully to the policy making deliberations in his community or state. To do so, however, he has to make a conscientious

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2282 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. IR 4, December, 1959.

a. Presented at the May 1959 ASCE Convention in Cleveland, Ohio.

1. Executive Secretary, Kansas Water Resources Board, Topeka, Kan.

effort to know and understand some of the basic legal, economic and social implications involved in the other interested disciplines. Unless he does so, he will have no basis for placing in proper perspective such contradictory phrases as "statutory law is patently unconstitutional" . . . "the economy cannot grow without the security of statutory law" . . . . "statutory law is inflexible and will make future changes in use impossible" . . . . "statutory law is needed to guarantee flexibility of use in the future" . . . . "statutory law is necessary in the public interest" . . . . "statutory law is purely a vested interest proposition." In view of such confusing statements, there would appear to be justification for a most elementary review of the basic concepts involved. The following comments deliberately approach the point of oversimplification in the hope that some useful perspective may be established.

The Basic Water Doctrines

The water laws of the several states are based on one or more of the following doctrines. With reference to surface waters, the doctrines are (1) the riparian common law of natural flow; (2) the riparian common law of reasonable use; and (3) the law of statutory appropriation. When applied to ground waters, they become (1) riparian (where the courts insist on thinking in terms of underground stream), (2) the English common law of absolute ownership, (3) the modified common law of reasonable use, (4) the correlative rights doctrine (fully distinctive only in California), and (5) the statutory appropriation doctrine.(1) Some students of law would undoubtedly point out that some of the foregoing do not represent basically different doctrines, while others would support further refinement, particularly with regard to the appropriation laws of the various states, some of which were originally rooted in custom and judicial decision rather than legislative action. For the purpose of this paper, all will be considered under the two main headings of common law and statutory appropriation law.

Generally speaking, the common law recognizes water rights by virtue of location either alongside or overlying the source to be used. Originally, the riparian holder was entitled to the maintenance of the adjoining water supply without diminution in quantity or alteration in quality except that upstream users of the same source were entitled to take from the source their natural wants for domestic needs. Inevitably, the pressures of economic growth have demanded modification of this concept, particularly with regard to surface supplies, so that under most common-law jurisprudence today riparians are assumed to have also the right to use water for extraordinary or artificial purposes so long as they do not interfere with the like needs of others.

Statutory appropriation law on the other hand establishes rights based on use rather than location. It arose in the western part of the nation and is the basis for part or all of the current water law in the 17 western states (some of its concepts have now been adopted by several eastern states).(2,3) Moreover, as generally conceived, the law protects the first user as against the second user, etc. All should note, however, that there is no one hard and fast "appropriation law" for it varies from state to state in accord with the specific statutes and/or judicial decisions in each state. Some of the major distinguishing characteristics of the two doctrines are as follows:

TABLE 1

	Common Law	Statutory Appropriation
Acquisition of right	Based on location	Based on actual use
Transfer of right	*Passes with land	May or may not pass with land transfer
Place of Use	Riparian lands	Riparian or non-riparian lands
Stability of right	Subject to change	Definite
Loss of right	**By transfer of land	**By transfer or non-use
Effect of diminished supply on right	Share proportionately with others	Direct obligation to prior users, no obligation to junior users
Character of right	Property right inherent in ownership of real property	Property right to the use of water

*Situation cited is general and limited exception thereto does take place so long as use remains on riparian land.
**Situation cited is general case and does not include special procedures of estoppel, adverse possession, etc.

The basic criticism of the common-law doctrine of reasonable use is that the rights of parties, resting upon reasonableness, are uncertain, thus discouraging economic development; that there is no way of taking into account the water needs of non-riparian persons; and that it cannot continue to cope with the increasingly complex pattern of water use developing in this country. Hence has come the upsurge of interest in some form of statutory law. Arguments usually advanced as to the need for change from common law suggest that statutory law will provide necessary investment stability, encourage water development, and insure its distribution to areas of need. Generally, the feeling in the more humid parts of the country is that some changes in the present common law must be forthcoming; but at the same time, there is prevailing fear that the route traveled by the west is not the path to be followed.(4)

Why Consider the Need for Statutory Law

The water needs of the country are met, of course, by resolving a combination of engineering, economic, and legal questions. So long as engineering and economic difficulties can be overcome within the framework of existing institutional limitations, they alone control development decisions. When they cannot be resolved on such a basis, effort is directed at modifying the legal groundrules to accomplish given objectives. To illustrate, drainage district and/or similar improvement district-type legislation provides a means for the majority to resolve problems which could not be resolved under strict common law wherein one owner may be prohibited from crossing another owner's property to obtain an outlet without prior consent.

It is submitted that in the resolution of problems of water use, engineering and economic considerations will eventually force evaluation of the need for modification in common-law concepts in practically every state. To date, this

problem has often been brought to the fore by the immediate impact of the rapidly growing enterprise of supplemental irrigation. Accordingly, the subject is being viewed in many states as a "vested interest" matter only. Nonetheless, objective interpretation of the growth in every field of water use leads to the conclusion that sooner or later many combinations of engineering and economic factors will be part of the over-all pressure. In some instances, quality considerations (temperature, chemical, or bacteriological) will be such that additional nonconsumptive use of the stream for process water cannot be tolerated under natural flow conditions. In others, vital new industries will not be able to run the risk of sizable plant investment in the absence of an absolute guarantee of certain quantity and quality standards. In still others, present recreational investments will no longer be able to withstand the impact of other uses within the limits of the available natural water supply. To be sure, engineering and/or economic answers to these problems will be possible, but not necessarily within the existing legal framework.

The point should be made that statutory appropriation law is just as susceptible to some of the foregoing pressures as is the common law; that the increasing demand for water will continue to be of concern in the west as well as in the east, and society will continue to wrestle with needed changes in institutional regulations. It would appear fallacious, however, to argue that the pattern set by the west is all wrong for the east or that the east has nothing to learn from the experiences of the west.

For example, the basic concept of statutory appropriation law as adopted in the west is to enable a potential water user to define the amount of water he is entitled to use and the relative position of his right to such use with respect to the rights of others. Security of investment is the byword. Notwithstanding other side issues that enter into discussions of water law, security will invariably be one of the primary factors leading to basic modification in the law anywhere. This is true whether new statutes are written to protect existing common-law uses from the encroaching effect of added extraordinary and artificial requirements or whether they are enacted to allow the development of new uses in the future. Accordingly, some of the basic factors underlying western water law are of importance whether or not the same pattern is followed in the east. These include constitutional concepts, provisions for future adjustments in the use patterns, and basic administrative considerations.

The Basic Constitutional Question

One of the first challenges encountered in any attempt to modify long-standing common-law concepts is that of constitutionality. Obviously, this is a serious question and whereas most engineers, including the writer, possess no license to practice law, they should understand the basic question that is usually involved. In fact, it appears possible that the engineer can contribute significantly to the disposition of this problem in the humid area states.

To begin with, notice should be taken of the fact that under common law there are two general categories of riparians: Those who have developed their rights to the source of supply, and those who for one reason or another have failed to put their inherent right to use. Presumably, any modification in the common law would in one way or another limit the future preferred rights of the riparians to a given source of supply. Inasmuch as the riparian rights are incidental to property ownership and inasmuch as the federal and state constitutions deny the taking of property without due process of law,

immediate problems are posed. They are not insurmountable, however, as witness the fact that in only 8 of the western states is statutory appropriation the exclusive controlling doctrine. In the other 9 states, common law was and/or is recognized to some extent.(5) As a matter of fact, it would appear that incorporation of some engineering viewpoints would allow the conclusion that this question might be easier to handle in the humid east than it was in the west.

The recent history in Kansas will serve to illustrate. Facing a need to encourage investment dependent upon the availability of water, the state enacted a Water Appropriation Act in 1945.(6) The immediate problem was that of being able to establish a mechanism for the acquisition of statutory rights; and to limit the future effect of unmeasurable and presently unused common-law claims. At the same time, existing uses had to be protected against the new appropriations and procedures had to be included to allow the person with an unused right just compensation for damage done. Admitting to certain oversimplification, the resulting legislative action may be summarized as follows. All uses in effect at the date of the passage of the act were termed "vested rights" and directives were established for the determination of these rights. All other waters were then open to appropriation subject to the other regulatory provisions of the appropriation act. Finally, provisions were incorporated so that common-law claimants (persons with unused common-law rights) could file suit for damages against those obtaining conflicting rights. Kansas is not the only state that has followed this course.(5,7)

Fundamentally, the problem above outlined is one of determining the extent of existing uses and limiting or otherwise defining the ultimate development of presently unused common-law claims. Learned legal counsel have indicated dubiousness as to whether the courts in the more humid areas would agree that the approach used by Kansas and other western states provides adequate opportunity for compensation in the fact of a more deeply entrenched common law.(8) Perhaps not. The writer is in no position to debate this point. Observation could well be made, however, that the "legal bear" seen by many can be placed in better perspective by considering the relative extent and nature of the water supplies in question. Undoubtedly, one factor that has alarmed many students of this problem in the eastern area is the concept that all waters not determined to be in "vested use" would be subject to appropriation. Immediate mental pictures of previously flowing streams being "dried up" come to mind. Overlooked entirely may be the fact that in many of the western states water under natural flow conditions is available but seasonally at best, and in others the firm natural yield may be nil for several successive years. The value of the unused right therefore is often more fiction than fact and undoubtedly western courts have recognized the physical dimensions of the problem. Admittedly, such physical situations may not exist in the more humid east. The main point to be made, however, is that in the more humid portions of the country the legal task of limiting the future extent of presently unused common-law rights may best be handled by specification of physical dimensions based on engineering evaluation of the duration flow or other water characteristics of the natural supplies. In such cases, the water available for statutory appropriation would be limited to that water over and above a predetermined minimum flow. Wherever this approach is tried, the engineering profession in each state should be active in such policy considerations; for active or inactive, they will have to work within the framework of what is done.

Security at the Cost of Rigidity

Aside from the constitutional questions encountered in most states, the next question that appears to be of primary concern in the humid areas is the concept that modification in the interest of security will lead unavoidably to an unalterable freezing of the water use pattern, both now and in the future. If true, this charge is a serious one, and any objective observer of statutory law must admit that in the absence of appropriate safeguards such a problem can develop. Nonetheless, the basic concepts involved can be lost in an aura of "sloganitis" if one is not careful. That the subject deserves more careful consideration is amply demonstrated by the fact that some students of economics argue effectively that statutory law is the key to a flexible pattern of water use.(9,10)

The common charge that statutory law is patently inflexible is apparently based on individual interpretations of the standard western concept of priority of use and its possible involvement with the concept of preferential use. Priority of use is exemplified in the western states by the concept of first in time is first in right. Interpreted literally, it means that he who uses the water first is entitled to protection against the demands of subsequent users. Generally speaking, "priority of use" operates independently of type of use. That is to say, the time of initial use and only the time of initial use determines the relative rights of two users. Such a time superiority can only be maintained by continued use, and the advantages of the time rights, in fact the entire right to use water, may be lost by nonuse. Rights to the use of water may be transferred to a new user and the time right maintained. In some states, this transfer may involve an entirely different type of use so long as it does not impair the quantity or quality of other recognized uses from the same source of supply. Under such a concept, there is an automatic mechanism for adjusting the future pattern to new and more pertinent needs. At the same time, the requirement that continued use is necessary to the maintenance of a right minimizes the possibility of a private interest holding a speculative right to a migratory resource. As will be noted later, the concept of priority of use also serves as a vital administrative guideline.

In the writer's opinion, experiences to date would indicate that in much of the so-called humid area the concept of "preferential use" is being confused inadvertently with "priority of use" and much more ado is being made over the subject than western practice would justify. Accordingly, any new consideration of statutory law in the eastern states is apparently accompanied by much jockeying by various groups as to what constitutes the proper preferential listing; e.g., should industry or agriculture come first. Most of this concern apparently stems from the belief that in times of water strife, preferential use rather than priority of use will determine the distribution of water; that is, when conditions are such that a common source of supply cannot continue to satisfy all water rights, holders of earlier rights for an "inferior" or less preferred type of use will be deprived of their rights without just compensation by holders of later rights for a "superior" type of use. This concept of "preferential use" is undoubtedly based on literal interpretation of the wordage in some western statutes which specifically state that in times of water strife a given use shall have preference over another. In actuality, priority of use continues to be the governing principle in such situations in the west. The preferential use provisions can be exercised against a prior holder of an "inferior" type of water right only upon payment of

compensation, thereby satisfying constitutional due process safeguards. Of particular interest in this regard is a decision of the Colorado Supreme Court upholding the prior use principle notwithstanding the powerful language in the state constitution regarding preferential listings.(11) What purpose does preference serve? In some states such listing is of importance in considering conflicting and simultaneously pending applications for water from the same source; and in others, it serves as a basis for the condemnation of inferior earlier rights for subsequent preferred uses. For these purposes, and keeping in mind that "priority" is the governing principle, it may be seen that a subsequent realigning of preferential uses can take place in response to relative future water needs without destroying the validity of existing rights. This is important, for the preferential listing must be operationally flexible in response to changing needs, and the stability of existing rights must be maintained. Paradoxically, the other interpretation that subsequent preferred rights could superside earlier inferior uses would provide no stability. Moreover, to this non-legal mind, such an approach would appear to endanger the constitutional due process rights of the inferior user--the same problem cited earlier only under a different hat.

When viewed as outlined above the writer cannot believe that priority of use or preferential listings as actually applied in the west are necessarily any more restrictive of future development than other proposals that have come to attention thus far. This is not to argue that the basic concepts of the west should be accepted without modification by any eastern state facing the need for some statutory guidance. A suggestion would seem appropriate, however, that the western approach is not without merit in this area, and that properly directed it has much more flexibility than is often believed to be the case. Some of the eastern states which have made their initial venture into statutory water law have attempted to obtain flexibility by other means;(2) for example, by introducing the concept of a water use permit for a limited period of time, by authorizing administrative discretion in times of water strife, etc.

Administrative Considerations

One matter should be clear. The initiation of statutory law will invariably lead to the need for the exercise of appreciable administrative responsibility by the appropriate unit of government. The costs thereof are not insignificant and are ample reason to argue against any premature adoption of statutory regulations requiring administrative supervision. Basic to any practical administration of water law is the need for a systematic or orderly bookkeeping of water use. In fact, this need might be far more important than the need for new water use legislation in many of the eastern states. Until the actual use picture is well documented, there may not be sound basis for weighing various legislative proposals. Accordingly, one of the first steps that a state could well afford to take in approaching the over-all problem would be that of providing for the initial cataloging and subsequent maintenance of water use data. Whether this is done by forced registration or via a basic planning program may be dependent on related questions of constitutional authority.

Reference to the need for data collection and/or generalized planning activities focuses attention on the fact that any attempt to administer statutory water law in the absence of comprehensive hydrologic data is like trying to navigate a ship without instruments in a dense fog. Administration, much like design, requires decisions today, but unlike the designer the administrator

seldom can refuse to act in the absence of adequate data. Society is demanding of public officials and often places a time limit on the period allowed for decision. The engineering profession should be especially concerned that any public policy which proposes to regulate water use provides for the establishment of a reasonable foundation of needed basic data. Far too often, apparently adequate legislation is not accompanied by adequate financial resources. The need for maintaining a broad based hydrologic planning program as an adjunct to administration cannot be overstressed and provision should be made to assure continuity of such activity by separate appropriation. Too often the administrative burden has forced subjugation of over-all planning when the funds therefor are not segregated. This is not to imply that it is possible to develop a master plan which will serve as an irrevocable administrative guide any more than it is possible to enact a perfect statute. Nonetheless, establishment and maintenance of a basic water account carrying water use projections a reasonable distance in the future can be a useful tool in the administration of statutory water law.

The granting of any administrative authority raises questions as to the degree of administrative discretion to be allowed. On what basis should an application for a water right be allowed? How much administrative detail should be specified by law? Too much detail would appear to make for a bad law. Some of the western laws, for example, specify that an irrigation right of so many feet per year shall be allowed. In the more humid east where the requirements for economic operation might be expected to vary widely across a state, it would not appear prudent to set such arbitrary limits, but to allow administrative discretion in considering individual applications. The situation is somewhat analogous to state-wide pronouncement of tolerable quality standards. Many will admit that such an approach to quality control is extremely ill advised and that administrative standards should be receptive to the flow characteristics, uses, and relative economic conditions of the individual stream. Suggestions that rights to use or permits to use be issued for a limited time period in the interest of flexibility should also be weighed in this light. The arbitrary establishment of a uniform time period irrespective of use and other relevant economic considerations might lead to automatic elimination of certain types of development. If the limited time concept is to be used, a better procedure would provide for establishment of a permit for a realistic period necessary to retire the initial investment, and legislative action should be directed at determining the basic principles to be considered in the administrative determination of the appropriate time period.

Of course the primary justification for governmental regulation of any kind is the public interest aspect of the migratory water resource. This poses a problem of defining the public interest in any stream. In Kansas, for example, the administrator must approve applications which "will neither impair a use under an existing right nor prejudicially and unreasonably affect the public interest." He is further directed to consider such items as "the area, safe yield, and recharge rate of the appropriate supply, the priority of existing claims of all persons to use the water, the amount of each such claim, and all other matters pertaining to such questions."(12) Engineers might be the first to question the advisability of this general language because terms such as "safe yield" are open to wide technical interpretation. Nonetheless, such an approach wherein the administrator's findings are subject to judicial review appears to provide a far better basis for flexibility and relative equity than an alternative which would attempt to predetermine technical findings or establish a uniformity of solution regardless of situation.

Of course, administrative law demands certain limitations and unlimited discretion cannot be given the administrator. This side of the coin may be illustrated by citing several of the modifications in western law that have been suggested for eastern consideration in an attempt to foster flexibility of use. Certain proposed legislation which has come to the writer's attention would give the administrator the authority to suspend certain permits in time of water strife and in the public interest. In essence, this is an attempt to assure that water is available for superior uses in times of water shortage. The need for guidance here is more pronounced than in the consideration of the original application because the opportunity for appeal is limited and the economic consequences of the administrative action will be immediate. Hence, legislative definition of the public interest is more critical. Without some guideline, the administrator would in effect be legislating rather than administering and obvious constitutional questions would arise. As noted earlier, western experience has indicated the courts will not tolerate the taking of earlier rights for inferior uses by later rights for more superior uses without compensation. Hence, in the absence of any formal adjudication, western administrative actions in times of shortage are clearly defined and water is made available on the basis of the priority record.

Iowa, in adopting a new permit system in 1957, granted administrative authority to suspend any permit for up to 30 days without notice (longer with 10 days written notice) when such action is necessary in an emergency to "protect the public health or safety or to protect the public interest in lands or waters against imminent danger of substantial injury in any manner or extent not expressly authorized by the permit, or to protect persons or property against such danger."(2) Only time will tell whether the courts decide this is enough guidance to justify direct administrative action. Undoubtedly, suspension on the basis of protection to public health would be more susceptible to reasonable administrative documentation than would suspension on the grounds of protecting general public interest. Either might well prove difficult in the absence of guiding principles to be used in determining the application of these terms.

SUMMARY

Change in water law, basic or slight, is inevitable whenever the engineering and economic requirements of water problems necessary to the resolution of existing social pressures cannot be met under current laws. At present, the subject is of concern throughout the country, with new emphasis in the eastern or humid area states where long-existing common-law principles are under attack. Changes are made in an attempt to better serve over-all public interest, but invariably one motivating factor is the desire for security, either to protect existing uses or to guarantee the investment in new development.

Much debate has centered around possible eastern utilization of the statutory appropriation approach so widely followed in the west. The charge that to do so would mean acquiring security at the price of flexibility is not believed warranted. In many ways, statutory law can be shown to be more responsive to the wants and needs of society. In all probability, too much emphasis is placed on the concept of preferential uses which in the long run can probably best be determined in the market place. Some proposals for statutory law in the eastern states would eliminate the concept of first in time

is first in right in an attempt to direct water to superior uses in times of strife. Whether acceptable administrative guides which will stand the test of judicial scrutiny can be developed to accomplish such an objective remains to be seen, and whether such an approach truly has added merit may be subject to question.

Leaving the basic question of constitutionality for individual state consideration, it may be concluded that where a state attempts to either limit or otherwise to determine how to provide for the unused riparian right, engineering appraisal of the situation may be helpful.

Essential to any consideration of water development, management, or regulation is the necessity of having accurate data on the type and extent of present use. Permissive or mandatory registration, as the appropriate case may be, would appear to be the first prudent step for any state faced with obvious conflicts in water use.

Adequately financed basic hydrologic planning programs are an integral part of proper administrative regulation of water use. A state unwilling to assume the cost thereof should question seriously the immediate need for such regulation. In those states facing a complex pattern of competing uses, attempts to legislate administrative detail should be avoided. Guiding administrative principles should be the key, with detail left to qualified technical appraisal of individual situations subject to judicial modifications upon appeal.

Seldom can any law be so forward looking as to identify all conditions of future development. Initial efforts which define and protect valid rights and establish procedures for initiating new uses subject to general public interest considerations is the major basic objective to be fulfilled. Continued evolution in water law must be expected everywhere. Regardless of location—west or east—social pressures will find ways of modifying existing laws to meet new requirements.

REFERENCES

1. Kansas Water Resources Board, "Report on the Laws of Kansas Pertaining to the Beneficial Use of Water," Bulletin 3, November 1956.
2. 57th General Assembly, State of Iowa, House File 553, (Now appears as part of Chapter 455A, Iowa Code).
3. Mississippi General Laws of 1956, Chapter 167.
4. Charles M. Haar & Barbara Moore, "Legislative Change of Water Law in Massachusetts," The Law of Water Allocation in the Eastern United States, David Haber & Stephen W. Bergen, The Ronald Press Company, pp. 1-48, 1958.
5. Wells A. Hutchins, "Western Water Rights Doctrines and Their Development in Kansas," University of Kansas Law Review, Volume 5, Number 4, pp. 499-516, May 1957.
6. Kansas Laws of 1945, Chapter 390.
7. Wells A. Hutchins, "Selected Problems in the Law of Water Rights in the West," U. S. Department of Agriculture Misc. Publication 418, pp. 42-44, 1942.

8. Robert H. Marquis, Richard M. Freeman, Milton S. Heath, Jr., "The Movement for New Water Rights Law in the Tennessee Valley States," Tennessee Law Review, Volume 23, Number 7, pp. 797-837, April 1955.

9. S. V. Ciriacy-Wantrup, "Concepts Used as Economic Criteria for a System of Water Rights," The Law of Water Allocation in the Eastern United States, David Haber & Stephen W. Bergen, The Ronald Press Company, pp. 531-582, 1958.

10. E. S. Bagley, "Some Economic Considerations in Water Use Policy," University of Kansas Law Review, Volume 5, Number 4, pp. 499-516, May 1957.

11. Town of Sterling V. Pawnee Ditch Extension Company, 42 Colo. 421, 94 Pac. 339 (1908).

12. Kansas Laws of 1957, Chapter 539.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

LEGAL ASPECTS OF GROUND WATER UTILIZATION[a]

Robert O. Thomas,[1] F. ASCE

ABSTRACT

This paper discusses the historical basis of water rights doctrines; their application to rights to the use of ground water; general considerations affecting the regulation of rights; various aspects of ground water utilization, including problems of recharge and water demand; and concludes with a presentation of some of the possible legal problem areas which may arise in planning and administering future ground water operations.

INTRODUCTION

As population, the general economy, and the standard of living continue to increase with the passage of time, the demands upon the available water supply also increase, oftimes in geometrical proportion. The attention of engineers and others immediately concerned with the provision of adequate water supplies is turning, with increasing momentum, to the possibilities inherent in the planned utilization of ground water storage capacity. In this paper, an attempt will be made to point out some of the more readily apparent legal aspects of such utilization.

Historical Basis of Water Rights Doctrines

Law originates in the efforts of a group to evolve rules governing the actions and relations of the members of the group between themselves as individuals, between members of the group and the group itself, and between members of more than one group. Much of our law pertains to the rights and duties of those who control or possess physical objects. Thus, we have a

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2283 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. IR 4, December, 1959.

a. Presented at the May 1959 ASCE Convention in Cleveland, Ohio.

1. Superv. Hydr. Engr., State Dept. of Water Resources, Sacramento, Calif.

tremendous body of law governing such material objects as land, buildings, machines, money, personal property, and — water.

Water, however, is peculiar in that it constitutes both a continuously renewable natural resource and a resource which is subject to dissipation with time. While it would be physically possible to capture and segregate a given volume of water, it would be of slight, if any, value to the owner as in the course of time it would disappear due to evaporation and, possibly, seepage. From the earliest times, it has been recognized that the value of water lies in its use — for drinking and washing, for dilution of wastes, for agriculture, navigation, recreation, and countless other purposes. The law concerning the possession and control of water relates principally to the rights and duties in the use of water, rather than to the physical control of the corpus of the water.

Water rights, as we use the term, are essentially rights to the use of water and as such, are recognized by law. Such rights, whether originating under riparian or appropriation doctrines, are rights in real property. Water rights, under both the riparian and appropriation doctrines are generally acquired and exercised in accordance with state laws governing water. The United States has, to some extent, recognized the power of each state to adopt its own system of water law. Congress has not established any procedures for the acquisition of such rights from the Federal Government, but, on the contrary, has required certain federal executive agencies to comply with state legislation affecting water rights. This requirement, however, has not been made specifically applicable to all federal agencies.

In the United States, two general systems of water right law are in existence. One system, prevalent in the eastern states, is the riparian system. The other, followed generally in the 17 arid western states, is known as the "doctrine of prior appropriation." Even in these latter states, however, the riparian doctrine, or system, is recognized, although to a considerably lesser extent. In some states it has been abolished by legislation.

The major distinctions between the riparian and appropriative doctrines arise from the conditions created by the contrasts in climate in the broad regions where they were first developed and applied. The humid eastern portion of United States generally has an annual average precipitation exceeding 30 inches. In the 17 arid western states, on the other hand, water deficiencies are accepted as normal during most years.

In the humid states, farmers generally may anticipate annual precipitation sufficient for their needs; indeed, there may even be an unused surplus remaining. Land ownership, and an accompanying riparian doctrine, may form logical bases for water rights in surplus water supply regions. Where irrigation, however, is encouraged, or practiced, a comprehensive system of legal rights and duties, as related to water, is generally required. The requirement for municipal and industrial uses also creates problems in developing adequate supplies. This has sometimes necessitated the development of distant surplus supplies as, for instance, the Croton and Catskill water supply systems of the City of New York. The riparian doctrine does not lend itself to such development.

On the other hand, in the arid west the annual rainfall at lower elevations is usually insufficient to supply the needs of developed valley lands. The mountain ranges, however, provide the means of storing the snowpack, and thus make available a source of water for beneficial uses. The locality with a requirement for water, however, is oftimes far removed from the region of

its occurrence. Consequently, a system based on appropriation, whereby water may be diverted, placed in temporary or carryover storage, and conveyed to the place of need, without regard to watershed limits, is a basic necessity.

The riparian system originally derived, not from the great body of common law as first inherited from England, but from early Roman law and its legal descendant, the Code Napoleon. There are many indications that the early English common law, while incorporating some aspects of what has come to be known as "riparian doctrine," included consideration of the "first in time, first in right" theory, a basic tenet of the doctrine of appropriation. As late as 1831, in the case of Liggins v. Inge, 131 Eng. Rep. R. 263, Chief Justice Tindall, of the Court of Common Pleas, wrote,

> "By the law of England, the person who first appropriates any part of the water flowing through his own land to his own use has the right to the use of so much as he thus appropriates against any other."

Writing in the California Law Review, in 1918, Samuel C. Wiel,(1) an authority on the development of American water law, said,

> "The word 'riparian,' as the name of a law of watercourses, made (its) first appearance in English reports in 1849 . . . In the Seventeenth century . . . a pleading of prescription or ancient custom was held to be the proper allegation; the law of watercourses was treated as resting upon prescription or ancient custom . . . (In the Eighteenth and Nineteenth centuries) the tendency was to pass from this to the doctrine of prior possession whether ancient or not — the doctrine of prior appropriation."

The institute of Justinian decreed that, by natural law, running water was owned in common by all free men. It naturally followed that an individual was precluded from exercising an exclusive use of the water supply. The Code Napoleon (French Civil Law) permitted a landowner to use water from a stream crossing or bordering his property, provided he restored it to the watercourse at its point of departure from his land. These expressions of the continental civil law are generally credited as the source of the riparian doctrine brought into American law in the nineteenth century by Justice Joseph Story.

The riparian doctrine, as we know it today, was given expression in decisions prepared by Justice Story of the United States Supreme Court and Chancellor James Kent of New York. Justice Story is thought to have used the word "riparian" for the first time in the case of Tyler v. Wilkinson, 4 Mason 397, in 1827. In 1828, Kent's opinion, developing the riparian doctrine, referred to most of the known civil law on the subject, including the Code Napoleon, the Institute of Justinian, and the treatise of Pothier. The riparian principles enunciated by those American justices first appeared to affect English decisions in 1849. In the precedent-setting case, Wood v. Waud, 3 Exch (England) 748 (1849) the English court quoted the American views with approval. Since that time, the case has been used as one of the earliest precedents in applying riparian law. The decision in Wood v. Waud is briefly summarized as follows:

> "We think . . . that the plaintiffs have received damage in point of law. They had a right to the natural stream flowing through the land, in its natural state, as an incident to the right to the land on which the

watercourse flowed; and that right continues, except so far as it may have been derogated from by user or by grant . . . . "

The California Supreme Court, in Lux v. Haggin, 10 Pac 674 (1886), summarized the law and the doctrine prevalent at that time as follows:

"The nature of the right . . . is usufructuary, and consists not so much in the fluid itself as in its uses . . . every riparian proprietor has a natural and equal right to the use of the water in the stream adjacent to his land, without dimunition or alteration . . . and to have the stream . . . flow as is wont by nature . . . undiminished except by its reasonable consumption by upper proprietors."

Water Rights in the Western States

Strangely enough, most of the western states, although deriving their background from the early Spanish exploration and settlement, followed early English leadership in the development of their statutory systems of appropriative water rights. The appropriation doctrine in the western states originated in the customs of the early day miners. Since water was a necessary adjunct to the working of claims, miners, as individuals and groups, diverted stream flows by means of dams, ditches, flumes, and other structures for storing and conveying the water to the point of use, often outside the watershed in which it had been diverted. Principles basically applicable to possession of property in general, and to mining development in particular, were applied to waters, such as priority of discovery and use, protection against other claimants, etc. By these means, the miners provided for the appropriation of water by diverting it from streams and devoting it to use, and for public recognition and protection of the property right which was thus asserted.

The importation of the English common law into the United States legal system, providing case law precedents where statutes were not applicable, resulted in the re-introduction of English precedents based on American cases which were, in turn, bases on continental legal codes. This was particularly confusing in states, such as California, where the state constitution provided for the adoption of common law precedents in all cases not covered by state statutes.

The adoption of English common law, as it related to water, placed the existing system of appropriation squarely at issue with the doctrine of riparian rights. The early appropriations of water had been made on what were, at the time, public lands. These appropriations were confirmed by Congress in the Acts of 1866, 1870, and 1877. The question of appropriative rights versus riparian rights appurtenant to private lands was resolved, basically, by the application of rules developed for the protection of possessory rights in property secured by prescription.

Various modifications of the riparian doctrine have been made in court decisions in the several western states. Since 1928, California has limited the riparian owner to a prior and paramount right extending only to the reasonable beneficial use of the water under reasonable methods of diversion. [Gin S. Chow v. Santa Barbara 22 P. (2d) (1933), Meridian Limited v. San Francisco, 90 P. (2d) 537 (1939), Peabody v. Vallejo, 40 P. (2d) 486 (1935)]. In Kansas, riparian owners have the primary right to use all the water they may require for domestic use and for watering livestock. Subsequently, after all other riparian landowners have had the opportunity for similar uses of the

available water, they are all equally entitled to an equitable share, for irrigation purposes, of water remaining in the stream. In South Dakota, a riparian owner may exhaust a stream for domestic use and stock watering, otherwise the rights of all riparians for other beneficial uses are equal. In Texas, riparian waters include only the ordinary flow and underflow of the streams, and waters of a stream above the level of highest ordinary flow are regarded as flood waters, to which riparian rights do not attach.

In some of the western states, however, the system of riparian rights has been discarded in its entirety. In these states, the only method of acquiring a right to the use of water is by appropriation and/or license from the state. In others, the rigidity of the riparian system has been eased to some extent by the application of the concepts of reasonable use, and reasonable methods of diversion of use, to the quantity of water needed to satisfy the requirements of the riparian landowner. These concepts have made possible the appropriation and diversion of surplus waters not required for use on riparian lands. The burden of proof establishing the existence of such surplus, however, remains the responsibility of the appropriator.

Utah has perhaps proceeded further in this direction than other states. For many years, the Utah courts had declared that underground water was owned by the overlying landowner. In 1943, however, the state laws regulating water were amended to provide that underground water was subject to appropriation. The amendment provided that,

> "All waters in this state, whether above or under the ground, are hereby declared to be the property of the public, subject to all existing rights to the use thereof."

In a subsequent case, Riordan v. Westwood, 203 P. (2d) 922, this statute was upheld and, in effect, all prior decisions in conflict were held to be based upon erroneous interpretations of law. Those who had previously used ground water had, of course, acquired a prescriptive right to continue such existing use. All other underground water, however, was subject to appropriation under the jurisdiction of the State Engineer. In its decision, the court said,

> "Until 1935, the decisions of this court treated the waters of artesian basins as percolating waters, and as such the ownership went with the owner of the ground where such waters were located . . . Our concept of what was and what was not percolating waters has changed greatly since that term was used in the early cases . . . in an arid state like ours it is very important that all of the waters be used in the most beneficial and economical way possible and that none shall be wasted. . . The question must be determined on our present standards and concepts and we must treat that question as though our concepts and standards had always been as they are now . . . "

Water Rights in the Eastern States

In the eastern states, water has not in the past been the key to the existence of a landed economy, as it has in the west. On the contrary, the very profusion of water supplies has been a major problem. In consequence, the principal purposes of water legislation have been the alleviation of flood problems, the provision of drainage, the improvement of navigation, and the maintenance of the quality of surface supplies. In more recent times, ground water development has, in some areas, resulted in the passage of legislation regulating the control and use of such supplies.

The establishment and maintenance of rights in and to the use of water has principally been accomplished by litigation in the courts. The resulting case law has essentially followed the philosophy expressed in the riparian doctrine, frequently modified, with the passage of time, by the concept of reasonable use. Rights to the use of ground water, originally part and parcel of the general property right of the overlying landowner, have gradually become identified with the concepts of reasonable use and the correlative rights doctrine.

Much of the legislation enacted in eastern states has resulted from the need to acknoqledge some special situation, rather than from the desirability of establishing general rules to provide for the equitable apportionment of water supplies. Examples of such legislation are the so-called "Mill Acts," stemming from the changes generated by the industrial revolution. These acts generally provided for the erection of dams or other obstructions to stream flow and for the assessment of, and compensation for, damages sustained by riparian proprietors. A number of states, e.g., Maryland, Wisconsin, Minnesota, North Carolina, Illinois, New York, New Jersey, and Indiana, have enacted legislation requiring permits to be secured from the state for the use of water in certain circumstances. These laws, however, appear to be quite general in their nature, frequently apply only to water used for certain purposes, and often are limited to specified regions within the state. There seems to be considerable doubt that they are sufficiently comprehensive in philosophy to constitute a reasonable basis for acquiring property rights in the use of the water taken under permit.

In 1954, Indiana, Kentucky, and Virginia adopted legislation declaring that the state possessed a general police power to provide for the protection and utilization of the water resources. These enactments, however, require additional legislation setting forth rules and procedures for implementing the policy declarations. This has been accomplished, in a limited way, by laws regulating certain uses of water by riparian proprietors on surface streams.

Mississippi, in 1956, established a system of water appropriation which, after providing for prior rights, made the use of, and rights in, surface water contingent upon compliance with the law and the administrative provisions regulating the acquisition of water rights.

In the period since World War II, accelerated interest in supplemental irrigation, the recurring danger of drought, and the demands resulting from increasing municipal and industrial use have occasioned a heightened awareness of the philosophy and principles governing the existence of water rights. Many of the eastern states have established commissions for investigation and study of water rights legislation. Proposed legislation has been subject to intensive public debate, and symposia on the subjects of water rights and utilization have been held in numerous localities. One of the most important of these was the conference in Washington, D. C., in 1956, on Water Allocation in the Eastern United States, sponsored by the Conservation Foundation. (See bibliography)

A Model Water Use Act has been prepared under the auspices of the University of Michigan Law School, and has been approved by the National Conference of Commissioners on Uniform State Laws. Although the general intent of this legislation is the development of the available water resources in the public interest, the treatment accorded to several important aspects of water use and control in the Model Act appears to be questionable or deficient. Among these are the following:

a) There does not appear to be any provision for state construction, distribution, or management of water resources.

b) Existing riparian uses are confirmed, but those which have never been exercised are disallowed. In areas where the legal concept of water rights has been based upon the riparian doctrine, this appears to be fraught with danger.

c) Except for existing uses of water, which are unlimited in duration, fifty years is the maximum term for which a right of water use may be secured. The power, or threat of power, to affect the economy of a large area or group of people by withholding their water supply is a potentially dangerous weapon to place in the hands of any administrative agency.

d) While the Act enumerates several beneficial uses of water, and implies that they (and others not named) are co-equal in the public interest, it also gives the administrative agency the right to deprive a lower beneficial use of a water supply in order to grant that supply to a higher beneficial use for a limited term. This seems to require that the administrative agency should somehow effect a ranking of beneficial uses in addition to granting unwarranted power of penalization and largesse in dispensing the available water supply.

e) It is very questionable whether, in the light of recent decisions of the Supreme Court, the Federal Government would be amenable to any provisions requiring limitation of the duration of water use permits and applicable beneficial uses.

f) It would appear that the Act provides, or must consider, three classes of rights, e.g., existing rights, Federal Government rights, and all others. Each of these would apparently be amenable to a different set of jurisdictional and legal principles. The resulting confusion in engineering, operation, and administration of water developments could be catastrophic.

g) Under the conditions established in the Act, it is doubtful whether financing could be secured for water development projects subject to revocable water use permits.

h) Last, but not least, in the sense of the subject of this paper, there is no apparent provision made for conjunctive use of ground and surface water supplies, nor for the planned utilization and management of ground water supplies.

Among other provisions of the Model Act which may give rise to serious question is the establishment of a state commission as the responsible agency both for planning the utilization of the water supply and for administering the system of permits for beneficial use. Regardless of the conscious effort to be fairminded that such a commission would undoubtedly make, there would remain a question regarding the influence of their own planning on their decision to grant or deny a permit for beneficial use. The dual scope of authority and administration would appear to engender basic conflicts.

It should be noted that the foregoing criticism of the Model Act is made solely for the purpose of pointing out possible areas of change or revision. The effort and thought which resulted in drafting the Act is recognized as an expression of the enlightened public appreciation of the place of water in our economy. The heightened interest in the law of water throughout the eastern

states can only have a beneficial influence on the specific legislation eventually adopted. Thorough discussion of the implications and probable results of alternative courses of action will undoubtedly promote the adoption of a system for administration of the available water supply which will result in action designed to promote best interests of the entire public.

Rights in Ground Water

Water beneath the surface of the ground has, until recent times, generally been classed, legally, as a subject separate and apart from precipitation and surface water supplies. Imperfect understanding of hydrologic processes has often led to such water being considered in the same category as a mineral, with the owner of the surface possessing definite rights to its extraction and use. As a case in point, the court held, in Acton v. Blundell, 12 Mees & W. (England) 324 (1843) that,

> ". . . we think the present case, . . . is not to be governed by the law which applies to rivers and flowing streams, but that it rather falls within that principle which gives to the owner of the soil all that lies beneath the surface; that the land immediately below is his property, whether it is solid rock, or porous ground, or venous earth, or part soil, part water; and that the person who owns the surface may dig therein, and apply all that is there found to his own purposes at his free will and pleasure; and that if, in the exercise of such right, he intercepts or drains off the water collected from underground springs in his neighbor's well, inconvenience to his neighbor . . . cannot become the ground of an action."

In other cases, attempts have been made to prove the existence of underground streams, flowing in "known and definite channels." In California, ground water which can be classified in this manner is legally regarded as identical to water occurring in surface streams; that is, subject to the dual imposition of riparian and appropriative doctrines. In making such a distinction in the classification of underground water, the courts have been at variance with hydrologic principles which recognize that all ground water (with minor exceptions, such as unrecoverable soils moisture, water in closed basins which is dissipated in excessive evapotranspiration, etc.) constitutes a part of the generally available water supply and has a common ultimate disposal with surface streams by means of outflow to the ocean or other large body of water, becoming inseparable from surface flows in the process.

Although the principles of the hydrologic cycle are now recognized in many jurisdictions, together with an understanding of physical laws governing flow, many courts still recognize legal distinctions separating and classifying (a) percolating water, (b) ground water in definite underground streams, and (c) underflow of a surface stream.

Percolating water may be said to be all ground water not included in one of the other classes. This unsatisfactory definition results from the necessity for development of opinion evidence in each case litigated. Various decisions have expressed the concept as,

> "vagrant, wandering drops moving by gravity in any and every direction along the line of least resistance,"

> "a vast mass of water . . . always slowly moving downward to the outlet or outlets," and

> "rain waters which are slowly infiltrating through the soil, or . . . waters seeping through the banks or bed of a stream which have so far left the bed and the other waters as to have lost their character as part of the flow."

The other legal classifications of underground water do not appear to possess a much greater degree of scientific exactitude. A definite underground stream must have characteristics similar to a surface watercourse. In other words, it must have a channel with well-defined limits, a source of supply, a measurable flow in a particular direction, and a substantial existence. These facts are generally established by opinion offered in proof of the legal allegations.

The underflow of a surface stream is perhaps the easiest to define. It consists of the water occupying pore space in the material lying beneath the bed of the surface stream, and supporting the surface stream in its natural state. It is generally required that the surface and subsurface flows be in contact, and that the subsurface water flow in a definite direction corresponding to the surface flow.

Rules of law applied to rights to the use of water differ in accordance with the above classifications of ground water. The complications often resulting from such arbitrary classifications are apparent in considering the case of a valley stream which is influent at one season of the year and effluent at another season. Yet courts will undertake the herculean task of defining the limits of influence of the stream. This is done despite the fact that the development of the basin and the over-all hydrologic conditions will combine to change the location of the boundary of influence from one day to the next.

Decisions have been rendered which hold that the underflow is a part of the stream and subject to the surface stream rights of use; that ground water flowing in definite underground channels is subject to the principles of riparian doctrine; and that "percolating water" (all other underground water) is subject, variously, to riparian doctrines or correlative right doctrines. Such decisions have often served only to complicate the use and development of ground water.

Several of the western states have abandoned past theories relating to the occurrence and ownership of underground waters and have instituted systems providing for the withdrawal and use of ground water by appropriation. New Mexico has applied this concept to a greater degree than other jurisdictions in the arid region. In that state, the existing water in underground storage has accumulated during the past ages. The average annual recharge is, in many cases, considerably less than the annual use. Consequently, the users, as a group, are actually mining the water and can anticipate a time when total exhaustion will have occurred. In basins where the annual pumpage exceeds the recharge, the State Engineer utilizes available knowledge and procedures to estimate the total quantity of recoverable water in storage. An annual pumpage quota, of sufficient magnitude to deplete the basin over a period of 40 years, is then determined. Permits to appropriate ground water are issued to prospective pumpers until the annual quota is attained, after which time no additional applications are considered. This raises the interesting question: just what do the people of New Mexico (irrigators, municipalities, and other water using activities) expect to do after exhausting their water supply?

The principle of absolute ownership of percolating water has been modified by numerous decisions in our courts. The modification appears to have had

its origin in decisions emanating from eastern jurisdictions [Bassett v. Salisbury Manufacturing Company, 43 N. H. 569 (1862) and Forbell v. City of New York, 164 N. Y. 522 (1900)]. The rule requiring reasonable use in conformity with the rights and requirements of others, established in these cases, later became known as the American Doctrine of Reasonable Use. The leading California case, Katz v. Walkinshaw, 74 P. 766 (1903), applied this rule to California conditions. The California doctrine of correlative rights founded in this decision states, in effect, that owners of land overlying a common water supply have mutual rights to the reasonable beneficial use of the water on the overlying land. The rights of each such landowner are held to be correlative with the rights of all other overlying owners, and should the supply be insufficient, the available water may be apportioned, by court decree, among all owners making use of the water. Surplus waters, not needed to meet the requirements of overlying lands, may be taken for use in other areas.

The doctrine of correlative rights has been confirmed and expanded in many subsequent decisions of the courts. An early summarization of this doctrine is found in Montecito Valley Water Company v. Santa Barbara, 77 P. 1113 (1904), as follows:

> "The main question which this court was called upon to consider, and did consider and decide, was whether the common-law doctrine of absolute ownership in percolating water, the cujus solum doctrine, was or was not, under the peculiar conditions existing in this state, subject to the just limitation under the doctrine of sic utere tuo, and this court recognizing the inevitable injury that must be worked to private interests whichever rule should be held to apply, after much deliberation decided that however differently the rule might be declared in states and countries well and regularly supplied by rainfall, in this state, with its great arid stretches, its seasons of drought, and its irregular meteoric water supply, percolating waters, when circumstances of hardship or injury should be presented in some particular case, must be held under the rule and doctrine of sic utere."

In most of the eastern states, the overlying landowner has usually been considered to possess unlimited rights of use in the ground water beneath his land. In a few states, notably Florida, Indiana, Maryland, Minnesota, New Jersey, New York, Tennessee, and Wisconsin, some legislative regulation of ground water use has been attempted. This has usually been brought about because of the necessity to control some specific use or to ensure the utility of a specific ground water basin, such as that underlying Long Island. The Minnesota legislation is comprehensive, requiring permits for any diversion or use of water, whether from surface or underground sources. However, few criteria for permits are given in the law, and the administration of the law has given it the effect of a registration rather than a regulatory statute.

Case law developed as a result of water rights contests in the east has been rather sparse, and many of the cases are quite old. The American Rule of Reasonable Use has frequently been looked upon with some favor, although there are many holdings to the effect that the overlying owner cannot, in the absence of legislation, be stopped from damaging his neighbors by unreasonable development. There have been few, if any, cases wherein the western doctrine of correlative rights has been applied.

A few eastern states have recognized that the heavy demands of industry and large urban populations are depleting the underground basins faster than they are being replenished. In general, the legislation has been directed toward limiting withdrawals from new wells, without provision for ground water reservoir operation or management. Such regulation merely delays the time of depletion or exhaustion of available supplies. Some legislation is only for the purpose of requiring recirculation of air conditioning withdrawals in order to prevent undue depletion. Some of the recent proposals for legislation in the eastern states have been quite comprehensive in scope, although there is no apparent unamity of thinking, particularly as regards rights in ground water and utilization of underground basins.

The "Raymond Basin" Case

An important extension of the doctrine of correlative rights, applied in the California case of Pasadena v. Alhambra, 207 P. (2d) 17 (1949), popularly termed the "Raymond Basin" case, was the concept of mutual prescription by and between all persons or agencies pumping from the underground basin. This concept is discussed in the following paragraphs.

When the available supply in a surface stream is, for all practical purposes, exhausted each year through application of the waters to beneficial use by riparian proprietors and/or appropriators, the fact is self-evident to all. This is not true, however, when dealing with water withdrawn from underground storage. In the latter situation there is, in addition to the annual accretion, a quantity of water in storage which, in some cases, may be drawn upon or mined for a number of years before the effects of withdrawal in excess of the safe yield become evident. The excess withdrawal, however, cannot be replaced unless pumpage is reduced to a quantity considerably less than the safe yield. At the same time, a considerable economy has usually developed on the lands, either overlying or distant, served by the pumped ground water.

In its decision, the court pointed out that the actual interference or invasion of each user's right occurred at the moment the safe yield of the basin was first exceeded. However, during the five year prescriptive period immediately following the first occurrence of overdraft, the earlier pumpers could have protected their rights by proceedings, injunctive or otherwise, against those responsible for the excess pumpage. After the completion of the prescriptive period, however, those causing the excess pumpage will have secured a prescriptive right against all other rights in the basin. At the same time, however, the original, or earliest pumpers, who first held overlying or appropriative (gained through use) rights had also secured a prescriptive right against those responsible for the pumpage in excess of safe yield. To this peculiar situation, the court applied the term, "mutual prescription."

In the Raymond Basin case, the court concluded that each water user had gained and held prescriptive rights against all others equal to the amount of water he had used continuously for a period of 5 years, and which he had not subsequently failed to use for a similar period. Since the total of these rights exceeded the safe yield of the basin, each user was enjoined from pumping more than his proportionate share of the safe yield, based upon the ratio of his rights to the total of all rights in the basin, the reduction in each case amounting to about one-third of the total pumpage. A supplemental supply of water must, of course, be available to the area, else the economy of the

region would be adversely affected. In this case, water was available through the facilities of the Metropolitan Water District of Southern California.

Regulation of Rights to the Use of Water

From the foregoing brief review of the historical development of rights to the use of surface and ground waters, it may be concluded that a water right, whether riparian or appropriative, is a species of property. In many jurisdictions, however, the rights to the use of water have been circumscribed to some degree, ranging from total public ownership of all water to restrictions governing the reasonableness of use or method of use.

However, a distinction exists between the adjustment, in specific cases, of relative rights as between individuals, and general regulation of rights for the common benefit. In the first instance, much of the case law pertaining to adjudicated rights is limited by the peculiar circumstances and conditions which led to the litigation. Although various decisions are relied upon as guides, their applicability must, in each instance, be determined by the courts.

On the other hand, regulation of rights in certain situations and for specific purposes, when related to the general good, has usually been upheld. When a common restriction is placed upon the exercise of a right, the relative rights as between individuals, remain essentially as they were before the restriction. This concept becomes directly applicable to the governmental legislation and regulation which will generally be required in order to permit the planned utilization of ground water basins for the conservation, storage, and distribution of the common water supply.

In those states where rights may be secured by appropriation, the applicable regulations generally provide for license or qualified grant by the state, limitation of quantity to that beneficially used, restrictions controlling type or place of use, and provision for reversion of the right in the event of non-use.

In states where the riparian system is the principal, or only, system recognized, statutes and court decisions have often required that the use of water be subject to the test of reasonableness. In those jurisdictions the riparian proprietor has been regarded as the possessor of a primary right of use, but his exercise of this right is limited by the condition that he not interfere unduly with the right of others to water not needed by him.

This being the case, there appears to be no insurmountable reason why restrictions on the use of property cannot be applied to water rights in the same manner, and with the same justification, as restrictions on the use of other species of property. Legal impediments to the right of an owner to make free and untrammeled use of his property, ranging from broad restrictions imposed by the Federal government to municipal ordinances, are common in our presentday economy. Examples of such restrictions are the activities of the Interstate Commerce Commission, Federal Trade Commission, state public utility commissions, and similar regulatory agencies. State water pollution and sanitary regulations, municipal ordinances concerning building heights, noise, dedication of certain areas in proposed subdivisions, and similar restrictions are further examples of the power to affect property rights.

If water is endowed with a public interest, it must yield to regulation. The right of the state to regulate property devoted to the public use has been conceded since the case of Munn v. Illinois, 94 U. S. 113, which established the

validity of a statute regulating grain elevators. From this concept, the whole field of public utility regulation has developed. Although a right to the use of water is usually considered to be vested, and consequently not susceptible of abrogation under the guise of general governmental power, it apparently can be qualified by appropriate legislation. As the need for water becomes more critical, means of diversion and use which tend to waste the resource will have to necessarily yield to regulation, even at some expense to the owner of the right. A method of use may be reasonable at one time or place but may become unreasonable as water needs become more critical.

Opposition to regulation will undoubtedly be experienced. It is only human to resent and repulse an attempt to restrict or qualify a right which has previously been enjoyed. In some areas, it will be necessary to base regulation of water rights on the police power of the governmental authority. In 1928, the constitution of the State of California was amended by popular vote. The amendment prohibited unnecessary waste of water and limited riparian rights to reasonable use under reasonable methods of use. Although the measure was passed by general vote of the electorate, and made no mention of the supposed state power supporting the provision, the courts deemed it necessary to resort to the general police power in validating the legislation. A typical case under the amendment was Gin S. Chow v. City of Santa Barbara 22, P. (3d) 5 (1933), wherein the court declared:

> "That the constitutional amendment now under consideration is a legitimate exercise of the police power of the state cannot be questioned. It is the highest and most solemn expression of the people of the state in behalf of the general welfare. The present and future well-being and prosperity of the state depend upon the conservation of its lifegiving water."

It appears that, in general, water rights are, or can be made, subject to appropriate regulatory action for the general benefit of the people and the economy. It is probable that the possessor of a water right is primarily interested only in the fact of regulation and its effect upon his exercise of the right. He would, of course, be interested in the determination that a governmental authority has a right, however grounded, to qualify his rights in his property. However, he will generally leave the determination of the basis for that governmental right, under whatever theory or philosophy, whether "police," "commerce," "general welfare," or other expression of power, to the legal profession.

Utilization of Ground Water Basins

The occurrence and movement of water under the surface of the ground has lost much of its aura of mystery in those sections of the country where the very existence and survival of the economy is dependent on the development and use of ground water. Wells and springs have long been a familiar source of water for domestic and agricultural uses, and industry is turning increasingly to ground waters because of the more constant temperature characteristics and relative purity. During the past half-century, development of ground water has proceeded apace, particularly since the development of electrically operated pumping installations for lifting water from considerable depths.

Use of Ground Water Reservoirs for Conservation Storage

The maximum development of the available water resources and consequent economic development of the area is realized when the available ground water

storage capacity is fully utilized for longtime holdover storage of flood waters. This can be accomplished by operating the ground water reservoir conjunctively with surface reservoirs. The principal difference between the usual surface reservoir operation and conjunctive operation with ground water storage is that the objective is the most economic joint reservoir yield rather than the attainment of a firm surface supply. In conjunctive operation, water is placed in underground storage as rapidly as the recharge capacity of the basin and the annual draft on ground water in storage will allow, drawing the surface reservoir annually to a low water stage. The resulting available surface reservoir storage capacity will then provide for the conservation of much of the peak flow which was formerly lost.

The surface reservoir serves to intercept and provide temporary storage for large flood flows, while ground water storage, generally of large total capacity and providing protection from evaporation losses, performs the cyclic storage function. The net result is that a greater portion of the available basin storage capacity is beneficially utilized, with a consequent large increase in the firm seasonal yield of water. It has been found that where surface storage alone may result in a yield of about 50% of the mean annual flow, the same amount of surface storage, operated in conjunction with available ground water storage capacity, would provide an annual yield of about 85% of the mean natural water supply. The cyclic storage capacity required, but not economically available on the surface, is developed in the ground water basins. Planned utilization of ground water storage capacity will thus contribute to the ultimate objective of providing adequate supplies of water to meet the ever-increasing demands of present-day civilization.

Use of Ground Water Reservoirs for Regulation

In recent years it has been recognized that, in providing for the efficient use of water resources, it is necessary to both increase the quantity available and to facilitate the repeated use of water for many different purposes. The planned utilization of ground water storage capacity will not only serve to augment the surface conservation storage capacity available for both seasonal and cyclic water conservation, but will provide facilities for storage and regulation of water supplies while in transit and at the point of use.

Ground water reservoirs are particularly suitable for the terminal storage of imported water supplies. They can be utilized for the purpose of regulating constant flows from aqueduct facilities to meet the variation in monthly demand in the service area. At the same time, they can be utilized as the distribution facility since, in general, the required water supply may be extracted at or near the point of use. Additionally, they comprise valuable units in a system designed for the recapture, and repeated use, of the same water supply.

Domestic, municipal, and industrial use, in addition to irrigation, maintenance of fish and wildlife, recreation, navigation, generation of hydro-electric power, and disposal of sewage and industrial wastes, among other beneficial uses, creates demands which can be met only through the mechanism of repeated cycles of water use and recovery. Some of these uses will occur in the mountain watershed, prior to the time the water is first taken into conservation storage for general use. Others will occur as the water is in transit from one storage facility to another. Still others will occur in the areas of valley use, where the ability of underground storage to receive, store, and

regulate unused water percolating from the surface is particularly important. Additionally, water supplies which have already been subject to some uses, but which are still of suitable quality, may be deliberately percolated in available spreading basins, in order to augment the supply.

Thus, through use of the regulatory capability of the ground water reservoir, the utility of the available water supply is enhanced. The use, recapture, and re-use of water can continue until such time as it is no longer susceptible of capture, or until the quality has deteriorated to the level where final disposal into the ocean or other large body of water is required.

Water Quality Considerations

Most water uses require supplies included within certain limiting criteria of quality. Failing this, harmful effects from the use of the water will result. On the other hand, most water uses tend to degrade the quality of the water and thus affect its suitability for subsequent or repeated use. When multiple use of the water supply is the desired result, the maintenance of water quality and prevention of water pollution become vital considerations in the planning and operation of water developments. The right of re-use of a water supply often becomes as important as the right to make the original use. Quality problems have been widely discussed elsewhere; they are mentioned herein only because there may be potential legal injuries stemming from the utilization of ground water storage.

The quality of ground water is of particular concern to agriculture and industry. In agricultural use, where water is evaporated or transpired, the minerals remain in the soil, being leached into the remainder of the ground water body by ensuing rains or by subsequent irrigation. Unless the salts are sufficiently diluted or removed, large areas of land may be adversely affected and sizeable volumes of valuable ground water storage capacity may be subject to severe damage. In industrial use, quality requirements for boiler feed water, water used in food processing, and water used in many chemical processes are vital to the successful operation of the business.

The water quality problem, from both a practical and a legal standpoint, is a serious consideration in ground water development and must be carefully considered in basin-wide water resources planning. The extent and type of degradation are dependent upon the mineral characteristics of both the water supply and the aquifer, and on the duration and quantity of flow. The resulting quality of the ground water varies with both location and time. Since quality criteria are recognized for most water uses, mineralization and possible degradation has a great influence on the value of the water for beneficial uses.

Recharge of Ground Water Storage Reservoirs

The attainment of the desirable objective of providing regulation of water supplies in underground basins is, to a considerable extent, contingent upon the successful accomplishment of recharge operations. Ground water storage capacity is generally more than adequate for conserving the available water supply, but the recharge capacity through the percolation area is often limited. The transmissibility characteristics of the underground aquifers are an additional factor of prime importance. For these reasons, surface conservation reservoirs must be operated in conjunction with ground water reservoirs, with discharges from the surface reservoirs regulated in accordance with the percolation, transmission, and storage capabilities of the underground basin.

The criteria controlling recharge operations are based on hydrologic principles. The procedures of utilizing such principles in administrative management are complex and difficult. A comprehensive plan for the management and control of water resources should provide for continuity of engineering investigation and the development of adequate hydrologic, geologic, and geographic data; the creation of agencies for management of the coordinated operations; and for the financial basis to support management programs. In most instances, these requirements cannot be provided in limited areas or under private auspices. The areas and functions to be covered are so extensive and affect such a broad sector of public interest that they appear to be feasible of accomplishment only through official agencies.

Legal Problems in Planning for Utilization of Ground Water Storage

The existence of present rights to water from ground water basins is an important aspect of the utilization of underground storage. If the attempt is made to coordinate usage of the storage capacity with the present pattern of withdrawals in a ground water basin, there probably will be conflict between the holder of existing rights to pumpage of ground water and the operator of the basin for reservoir purposes.

The operation will entail primary dependence on, and draft from, ground water supplies during drought periods with oftimes extreme lowering of the water table. Conversely, during an ensuing wet period, the quantity placed in storage would raise the water table to a high level. It is probable that individual users will not complain during such periods as the water table is held at high levels and they consequently receive the benefit of lowered costs of pumping; however, at such times as the water table is deliberately lowered in order to provide firm supplies during dry periods, the administrative agency responsible for such operation might be the target of lawsuits or injunctions on the part of local water users. Legislation providing for the utilization of underground storage capacity should also provide for appropriate adjustment with the owners of existing rights. Necessary water supplies could then be provided to the overlying service area by the agency operating the basin.

There appear to be two broad types of artificial recharge operations. The first occurs where the safe yield of the basin underlying a given service area is insufficient to provide for the water requirements of the area. The second type contemplates the use of the basin underlying a given area for the temporary holdover, or regulatory storage, of water in transit, or for terminal storage of imported water. There may well be a third group wherein the characteristics of the two mentioned above are mixed in varying degrees.

What, then, are the rights of a landowner in one of these areas? It appears to be a settled principle of law that the owner of land owns all that occupies the space beneath his land. Water, however, has been excepted from this ownership in many jurisdictions through the operation of judgments in the courts. However, the general ability of the landowner to develop, or to sell or lease to others, separate and apart from use of the surficial contours of his property, the rights to the minerals which may be found beneath the surface has been consistently upheld. In some jurisdictions, the right of the land owner to control the use of the air space above his land, and even to prohibit

its use by low-flying aircraft, has been upheld to a certain extent. The question arises, does he have similar rights in the interstitial voids which exist between the solid particles of matter beneath his land? There is no question but that the owner must be recompensed if it is desired to store water above the surface of his land. Is he also entitled to some recompense by the agency effecting the same result beneath the surface?

Political and governmental legal principles provide that when the majority of landowners in a given area join together in the formation of a municipal corporation, district, or other governmental agency, all owners within the boundaries of the new agency become subject to the agency's jurisdiction. In so doing, they give up certain rights in the use of their property which were previously held. Examples of such grant of privilege are the right of a municipality to enforce zoning laws, building codes, and other ordinances which take away from the owner a part of that which previously was his recognized privilege. He is also subject, in certain types of districts, to liens against his property by reason of bonds or assessments, even though he personally may not have been in favor of the imposition of such bond or assessment. It seems that the general theory upon which this dimunition of freedom to enjoy real property is based is that the landowner receives certain other benefits, such as police and fire protection, educational services, and other miscellaneous services rendered by the governmental agency for the benefit of all. Can this theory be extended to cover the use of the storage capacity in the underground basin by an agency which is organized for that purpose?

Use of the storage capacity to augment the supply available to the overlying landowner would probably be regarded as a benefit for which he gave up a part of his right of ownership of all beneath the surface of his land. However, if the use of the storage capacity beneath his land was for the benefit of a distant area, separate and apart from the area in which his land was located, would he then be entitled to recompense for what might be called, for want of a better term, involuntary condemnation?

Assume two ground water basins, one of which receives a portion of its annual recharge by underflow from the second, or higher, basin. The lower basin has a historical safe annual yield of 40,000 acre-feet per year. This is insufficient to provide for the requirement of the overlying lands and the landowners have consequently been considering the purchase of a supplementary supply of 10,000 acre-feet per year at a cost of $10.00 per acre-foot. The upper basin forms a ground water recharge district and secures a supply of water for the purpose of recharging the underground aquifers. As a result of this recharge, the underflow to the lower basin is increased by 10,000 acre-feet per year. This increase relieves that basin of the necessity for an annual payment of approximately $100,000 for this quantity of water.

Since it is not possible to prevent the movement of water underground in the direction of the hydraulic gradient, the courts in some jurisdictions, notably in California, have followed the rule of correlative rights in percolating waters and have attempted to identify all users drawing from a common supply. The question which arises in cases similar to that described above is, how should the extent of the boundaries of ground water recharge districts be determined? Should they be limited to single basins or should they be extended to cover all possible areas which are, or may be, affected by underflow from any part of the entire area?

Another question which arises in the planned operation of ground water basins is the case of a basin in which a portion of the surface area, lying at

lower elevations, was, in a state of nature, swamp land. The swamp area resulted from rising water in the lowermost portions of the basin. After commencing pumping operations, the water table beneath the swamp area was lowered to a considerable extent, the land was reclaimed, settled, and large investments were made in farming enterprises. A ground water recharge district is now organized and, depending upon the boundary chosen, it may or may not include this former swamp area. Water is imported from sources outside the basin and percolated to the underground aquifers for storage. The water level rises, and although the lands in the upper part of the basin are still in excellent condition for farming operations, those in the lower part become subject to high water table conditions and even, in some instances, to standing water. Since this is a natural phenomenon, do the owners of these lands have any basis for recompense? Would they be entitled to the maintenance of a condition conducive to intense utilization, resulting from the original pumping of water for use on higher lands and upon which they relied when developing their own lands?

An important legal problem associated with recharge operations is the identification of the water that has been placed in underground storage. Another is the determination of the effect of recharge activities on the basin and on the water users deriving their supply from the underground sources. It is necessary to know how much water has percolated, and its direction and rate of travel. It is also necessary to ascertain the effect of recharge operations on the basin so that determinations of injury or benefit, if any, to overlying owners can be made. Water quality aspects of the recharge operation are another extremely important factor. Because of the deficiencies in the present state of knowledge, the variables involved, and the scope of the required data collection and research activities, definitive conclusions on the effect of ground water recharge activities are not easily determined.

The deliberate artificial recharge of a ground water basin is recognized in the California Water Code, which states:

> "The storing of water underground, including the diversion of streams and the flowing of water on lands necessary to the accomplishment of such storage, constitutes a beneficial use of water if the water so stored is thereafter applied to the beneficial purposes for which the appropriation for storage was made." (Section 1242)

The principles underlying the statutory authority have been recognized and upheld by the courts in the case of City of Los Angeles v. City of Glendale, 142 P.(2d) 289. The City of Los Angeles has, for many years, imported water into southern California from the Owens River basin, to the east of the Sierra Nevada. A considerable quantity of the imported supply percolates to the underground basin as a result of both deliberate and incidental artificial recharge operations. The cities of Burbank and Glendale established well fields drawing from the underground supply. Los Angeles then sued to prevent the other municipalities acquiring a right to the imported supply conserved in such underground storage. In its decision, the court held,

> "(The City of Los Angeles) had a prior right to the use of water brought to the San Fernando Valley. It did not abandon that right when it spread the water for economical transportation and storage . . . once within the basin, enroute to diversion works, it was in effect within (the city's) reservoir . . . . It would be harsh to compel (the city) to build reservoirs

when natural ones were available . . . . Part of (the water) was spread . . . in gravel pits and "spreading grounds" . . . the remainder . . . was sold to the farmers of the San Fernando Valley, and as forseen . . . 27-1/2 per cent of it also sank beneath the surface and joined the normal and spread waters."

Other cases bearing on the right of recapture of seepage or return water after it has left the boundaries of a project (providing such recapture can be proved to have been a part of the planned operation of a project) are Ide v. United States, 263,U. S. 497, involving a water project in Wyoming; and an Idaho case, United States v. Haga, 276 Fed. 41.

Organization for Ground Water Basin Operation

It is generally agreed that all who benefit from a project, such as the recharge of the ground water basin, should share equitably in the costs. Existing irrigation, water conservation, and similar districts were generally organized to make surface water supplies available to the district area. Consequently, the boundaries of such districts frequently do not coincide with the boundaries of underground water basins. Districts covering a portion of a ground water basin frequently find that deliberate or incidental artificial recharge, resulting from their activities, produces appreciable benefits for many landowners outside the district by reason of the rise in the ground water level.

An exact solution for this difficulty would be the organization of a district with boundaries corresponding with the limits of the underground basin. Where no existing districts are organized, this would be a simple process. In areas where part of the basin is included in organized districts, an overall district might be established, either replacing or including existing agencies. Where inclusion is effected, however, difficulties due to dual taxation of lands in the existing districts might ensue. A possible remedy might lie in the establishment of a new district in the unorganized area only, followed by organization of a supervising, or coordinating, district having only a small staff and no operating responsibility.

Appropriate district organizations for ground water development will depend, of course, on the legislative authorizations incorporated into the law of various states. Irrigation and other types of districts often have general powers which may be interpreted to include the recharge of ground water basins and the performance of the conjunctive operation. Such districts, however, may encounter problems in the distribution of costs in accordance with benefits in cases where the benefits are unequally distributed. This is particularly important where benefits transcend district boundaries. Although a rise in the water table would tend, in some instances, to affect land values, the result would not necessarily be proportional to location or size of parcel.

Legislation authorizing the formation of ground water operating districts should provide for:

a) the method of forming the district,

b) the appointment or election of a governing board,

c) the purchase of, or other adjustment of conflicts with, existing water rights,

d) the conservation of water supplies by maximum use of the available storage, including artificial recharge,

e) the development and transportation, or purchase, of water supplies from without the basin,

f) the development and distribution of water supplies within the basin,

g) the imposition of general taxation in order to share the burden of costly supplies among those who ordinarily secure their supplies by other means,

h) the treatment and conservation of waste waters,

i) the coordinated and conjunctive operation of ground water with surface storage,

j) special arrangements with, and/or assessments on, those continuing to pump from the underground basin,

k) sound methods of financing for needed works and improvements.

In California, legislative authority and sanction has been given to a form of district organization specifically modeled to meet the peculiar requirements associated with ground water basin operations. These districts, known as Water Replenishment Districts, may be organized in regions where the existing underground water supplies are insufficient to meet demands placed upon them and where further excessive pumping without replenishment will destroy the usefulness of the underground reservoir. At the present time, the organization of such districts is limited to the arid southern part of the state, although it is anticipated that the legislation will be made applicable to other areas as the need arises.

Formation of water replenishment districts may be commenced by petition signed by at least ten per cent of the registered voters residing in the proposed district. The completed petition is referred to the State Department of Water Resources for action. The Department makes an appropriate investigation, followed by hearings, for the purpose of determining (a) whether the persons or lands in the proposed district will actually benefit by planned utilization of the ground water basins, and (b) whether the boundary of the proposed district includes all persons and lands which rely on the underlying ground water supplies. The Department may modify the boundaries of the proposed district to include or exclude certain lands in accordance with the benefits derived. An unfavorable finding will bring the proceedings to a halt, although a new petition may be filed after a lapse of at least six months. A favorable report by the Department, however, will set in motion the statutory proceedings required to complete the organization of a district.

Water replenishment districts, as authorized in California, may levy assessments in proportion to the quantity of water pumped from the underground reservoir. This is important in providing for the equitable assessment of the benefit to holders of appropriative and prescriptive rights to use water on non-overlying lands. The districts also have the power to purchase water from sources outside the district and distribute such water in exchange for the cessation or reduction of ground water extractions. This permits replenishing and managing the ground water supply within the district. The districts may also spread or inject water into underground aquifers and "store, transport, recapture, reclaim, purify, treat, or otherwise manage and control water for beneficial use of persons or property within the district."

Administration and Control of Ground Water Utilization

In all states in which planned river basin development, including ground water utilization, will take place, some form of water rights doctrine already exists. This doctrine may be solely the appropriation doctrine for surface streams, or it may be a combination of appropriation and riparian doctrines, as in California. In the east, the riparian doctrine generally prevails for surface water supplies, while ground water is usually governed by either the "absolute ownership" or the "reasonable use" doctrine.

This being the case, it is imperative that legislation promoting ground water utilization provide adequate protection to prior rights to the use of water and establish an equitable basis for compensating owners of rights which are acquired in order to accomplish successful operation.

The recognition and ratification of existing rights is generally accomplished by "saving" clauses in pertinent legislation. The question of compensation, however, may be handled on an individual basis by the courts, which may lead to inequitable settlements with different parties in cases where the facts are essentially similar, or may be guided by principles laid down in the law and administered by either a single agency or by the courts. The procedures generally followed in the valuation of lands and improvements acquired for public purposes would seem to have applicability insofar as acquisition of such classes of property would be required. The valuation of a water right held by an overlying owner, however, would appear to be somewhat more difficult than appraising an item of tangible property.

A suggested method of evaluating this right, consists of establishing the historical annual cost of pumping, per acre-foot to the overlying owner and subtracting such cost from the proposed price at which a supply will be furnished to his lands. The balance would represent the additional cost of such replacement supply. This amount could then be capitalized for an appropriate period, say fifty years, and the resulting total termed the value of his right. This, then, would be the amount he would receive as compensation.

Legislation providing for the increased use of ground water storage capacity in the conservation and regulation of water supplies should also provide for the means of properly supervising such utilization; for the organization of operating agencies (discussed in a previous section); for financing such operations on a sound and logical basis; and for the control of the quality of water in underground storage.

It is felt that, because of the oftimes large geographical coverage required for ground water operations and the frequent necessity of coordinating conservation activities in widely separated regions, control and supervision should not be delegated to an agency of less than statewide authority. It is not necessary that such agency actually design, construct, or operate conservation projects, although that might be desirable in certain circumstances. The agency should, however, have the responsibility to (a) review, (b) approve, modify, or disapprove, (c) supervise, (d) coordinate, and (e) regulate the organization, plans, financing, construction, and operation of districts or other agencies engaged in the development and utilization of ground water for beneficial use. This would ensure uniform standards for the protection of the public interest in the development of vitally needed water supplies.

The same, or at least a second, state agency should have the responsibility for protecting the quality of ground water supplies. This should extent to regulatory authority over the disposal of liquid or other wastes which would

tend to adversely affect water quality; and authority to restrict, or otherwise control, ground water operating practices which would permit the intrusion of degrading waters into otherwise usable supplies. If this latter agency is not a part of the overall control authority, explicit legislative provisions for adequate coordination between the two agencies would be required.

A thorough review and analysis of the engineering, financial, and economic feasibility and justification of proposed ground water recharge and conservation projects will do much to enhance their desirability and attractiveness to the public. Many of the legal considerations involved in ground water development will necessarily be solved in the project formulation process. Comprehensive basic legislative authority, however, will be the cornerstone upon which the maximum conservation and development of water resources, particularly ground water resources, will be accomplished for the greatest benefit to all concerned.

ACKNOWLEDGMENT

The opinions and concepts expressed herein are those of the writer and are not to be construed to represent the policies or programs of the California Department of Water Resources. Grateful acknowledgment is made to the many who have, wittingly or unwittingly, contributed to the material contained herein. Special appreciation is due Mr. Martin McDonough, Attorney-at-Law, Sacramento, California, and to Mr. Russell R. Kletzing, Associate Attorney, California Department of Water Resources, who reviewed and commented upon the original manuscript.

The following bibliography enumerates many of the sources which were consulted during the research into the legal complexities surrounding the subject of water in general, and ground water in particular.

BIBLIOGRAPHY

1. "California Law Review," Volume 6, 1918, pp. 245-46, University of California, Berkeley, California.
2. Bingham, Joseph W., "Cases on the Law of Water Rights," Bobbs-Merrill Company, 1916.
3. Callahan, Chas. C., "Principles of Water Rights Law in Ohio," Ohio Department of Natural Resources, 1957.
4. Clyde, Edward W., "Current Developments in Water Law," Irrigation Districts Association of California, 1958.
5. Holsinger, Henry, "Some Legal Aspects of Ground Water and The California Water Plan," Journal, American Water Works Association, April, 1955.
6. Hutchins, Wells A., "The California Law of Water Rights," Printing Division, State of California, 1956.
7. Legislative Research Commission of Kentucky, "Water Rights Law in Kentucky," Frankfort, Kentucky, 1956.

8. Thomas, Harold E., "Water Rights in Areas of Ground Water Mining," United States Geological Survey Circular 347, 1955.

9. Thomas, Robert O., "Planned Utilization of Ground Water," (to be published as a chapter of the Ground Water Manual of the American Society of Civil Engineers).

10. Timmons, John F., O'Byrne, John C., and Frevert, Richard K., "Iowa's Water Resources," Iowa State College Press, 1956.

11. Towner, Porter A., "Mutual Prescription - Threat to Vested Rights to Ground Water," Irrigation Districts Association of California, 1957.

12. The Conservation Foundation, "The Law of Water Allocation in the Eastern United States," edited by David Haber and Stephen W. Bergen, The Ronald Press, 1958.

13. University of Michigan Law School, "Water Resources and the Law," Ann Arbor, Michigan, 1958.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

EVALUATING FURROW AND CORRUGATION IRRIGATION[a]

Dell G. Shockley,[1] F. ASCE

INTRODUCTION

There are now nearly 37 million acres of irrigated land in the United States. The greatest single use of fresh water in our country is for irrigation. Our irrigated area has increased over 40 percent since 1949. Further increases are expected—and will be needed—to meet the food, feed, and fiber requirements of our expanding population. The conservation use of our irrigation water supplies, therefore, is imperative.

The use of water for irrigation often is relatively inefficient. Many farm irrigation systems, both surface and sprinkler, are poorly adapted to the soils and topography. Even where well-designed systems have been installed, improper operation has sometimes caused a wasteful use of water and, of even greater importance, irreparable land damage from soil erosion.

Poor farm irrigation layouts and improper irrigation water application practices usually result in reduced crop production and lower net incomes. Excessive water applications may leach watersoluble nutrients beyond the plants' reach. Often heavy irrigations raise the ground-water level and may completely waterlog lower lying lands. Many acres in the western states have been taken entirely out of production by waterlogging and salt accumulations.

Erosion may have an adverse effect on production even though not a single ton of soil is lost off the field. Too-large irrigating streams may erode soil from the upper portion of the field and deposit it on the lower portion—often inhibiting optimum crop production in both portions. The soil depth in the upper portion may become too shallow for adequate root development, and the finer soil particles moved to the lower portion of the field may reduce production by inhibiting water penetration.

Technicians of the Soil Conservation Service are continually evaluating farm irrigation systems and farm irrigation water application practices in an

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2284 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. IR 4, December, 1959.

a. Presented at the February, 1959, ASCE Convention in Los Angeles, Calif.

1. Irrigation Engr. Eng. and Watershed Planning Unit, Soil Conservation Service, U. S. Dept. of Agriculture, Portland, Ore.

effort to assist farmers to make efficient and safe use of their soil and water resources. These evaluations, in general, follow the procedures described in Agriculture Handbook No. 82, "Methods for Evaluating Irrigation Systems," USDA, Soil Conservation Service, Washington, D. C., April 1956.

The purpose of this paper is to amplify the evaluation procedures for furrow and corrugation irrigation, given in Handbook 82. It includes a discussion of the irrigation principles involved in furrow and corrugation irrigation and presents a simplified procedure for making tentative or preliminary evaluations. Similar "short-cut" procedures are applicable to other methods of irrigation but are considered to be beyond the scope of this paper.

Definition And Water Application Principles

Furrow irrigation is a partial surface flooding method of irrigation. The irrigation water does not cover the entire surface of the field. Rather, it is applied in small channels or furrows between the plant rows or beds. When used for the irrigation of close-growing, non-cultivated crops, such as alfalfa, clover, grass, or small grain, these small channels are called corrugations. The water soaks into the soil along the furrows (or corrugations) and spreads laterally to irrigate the areas between the furrows.

The time that water must be run in the furrows is dependent upon the amount of water required to refill the root zone, the intake rate of the soil, and sometimes the spacing of the furrows. Also, since water will not reach the lower ends of the furrows until it has been run into the upper ends of the furrows for some time, the total time of irrigation must include this "advance" period. For uniform water distribution, it is desirable that the advance period be as short as possible. The generally accepted criterion is that the water reach the lower end of the run in not more than one-fourth of the time required to infiltrate the desired amount of water into the soil.

On a given field, large irrigating streams will advance faster than smaller streams. Therefore, the distance the largest feasible stream will advance in one-fourth of the required infiltration time is the maximum allowable length of run. The stream used must not be so large as to cause erosion and also must not exceed the capacity of the furrow.

Initial irrigating streams must greatly exceed the intake rate of the soil in order to advance rapidly. Therefore, when the water reaches the lower end of the run the streams must be adjusted or "cut back" to prevent excessive waste from surface runoff. As the intake rate decreases during the irrigating period further stream adjustments may be needed. Sometimes part, or all, of the stream adjustments can be eliminated by collecting the runoff water and pumping it back to the head ditch for re-use. This is merely a substitution of power for irrigating labor. The important thing is that the water is kept under complete control and is not wasted off the field.

Evaluation Procedure

A tentative or preliminary evaluation of furrow irrigation can be made from a few simple field observations. This often is all that is needed to determine whether or not a field is being satisfactorily irrigated. If these preliminary observations indicate unsatisfactory conditions, a more detailed evaluation, as described in Agriculture Handbook 82, may be needed to pinpoint required corrective measures.

Step 1.

Estimate how much water is needed to refill the soil-moisture reservoir. This usually is done by the "feel" method described in Handbook 82. Often the moisture requirement can be satisfactorily approximated from a knowledge of crop consumptive use rates and the elapsed time since the last irrigation.

Step 2.

Estimate the amount of water being put on the field–in terms of acre inches per acre (inches depth). If water is delivered from a well, the farmer usually will know the approximate discharge. Canal deliveries often are measured at the farm headgate. Some farm systems have weir installations or other structures where flow measurements can be made. In other cases it may be possible to estimate rates of flow from measurements of velocity and ditch cross-section.

Flow rates can be converted to delivered volume by using the approximate relationship:

1 cfs for 1 hour equals 1 acre-inch.

The time water is run onto the field can be determined by observation or by asking the irrigator. If the farmer cuts back his furrow streams or otherwise adjusts the rate of water delivery, separate computations of volume must be made for each rate of flow and time involved. The sum of these volumes will equal the total volume delivered.

The area covered can be determined by pacing the width and length of the field or the portion of the field covered by the particular "set" of water. Sometimes it is more convenient to count the number of furrows "set" and multiply by the average furrow spacing to obtain the field width. The width times the length divided by 43,560 equals the area in acres. The acre-inches delivered divided by the number of acres covered equals the average depth of water delivered to the field.

Normally the average depth of water delivered onto a field should be in the range of 130 to 175 percent of the depth required to refill the soil-moisture reservoir (step 1). However, where "pump-back" systems are used to take care of surface runoff (tail) water, deliveries of over twice the required amount may be satisfactory.

Step 3.

Determine the average time required for the furrow streams to advance to the lower end of the run. Normally the advance time should not exceed 1/5 of the total time water is run onto the field (1/4 of the infiltration time). Check for signs of furrow erosion–particularly near the upper end of the field where streams are largest. If the advance time exceeds the 1/5 criterion, check on the feasibility of using larger furrow streams. If the furrow streams cannot be increased because of erosion or capacity limitations, determine the distance they will advance without exceeding the time criterion. If the streams used are causing significant erosion, determine what size furrow streams could be used safely. Determine the advance time for these streams or the distance they will advance within the allowable time limit. Often adequate information on advance time can be obtained from the irrigator. If it appears desirable to change stream sizes it may be necessary to time the advance of the trial stream.

Step 4.

Estimate the average depth of water infiltrated into the soil during the irrigation. For a good irrigation, the average intake should equal or slightly

exceed the depth of water required to refill the soil-moisture reservoir. If the water is on the lower end of the field long enough for an adequate irrigation, there will be an excess intake opportunity time of some magnitude at the upper end of the field and some deep percolation loss. However, if the advance time does not exceed 1/4 of the intake time, the over irrigation at the upper end should not be excessive. Average field intake may be estimated from intake rate measurements or from field inflow-outflow measurements of both. The procedure for each method is described below:

Intake Rate Method. Near the end of the irrigating period—usually sometime in the last quarter of the period—make inflow-outflow measurements of one or more representative furrows or furrow reaches. The difference between inflow and outflow will represent rate of furrow intake. The furrow intake rate should be expressed in terms of gallons per minute per 100 feet of furrow. The furrow rate can be converted to equivalent field intake rate (inches per hour) by dividing by the furrow spacing (in feet).

The above field intake rate will be the instantaneous rate at the end of the irrigation. Since intake rates decrease as time increases, the average rate for the period of irrigation will be somewhat higher than the instantaneous rate at the end of the irrigation. The difference usually will be greatest on fine-textured soils that characteristically have steep intake rate curves, and least on coarse-textured soils which generally have relatively flat intake rate curves. The average intake rate, therefore, can be approximated from the final rate by multiplying by a soil factor. From observations of the general shape of intake rate curves for soils of different texture, the multiplying factors have been found to be about as shown below:

Soil Texture	Soil Factor
Fine and moderately fine clays and clay loams	1.50
Medium and moderately coarse silt loam to sandy loam	1.33
Coarse and very coarse loamy sands and sands	1.20

The average intake rate should be multiplied by the average intake opportunity time to obtain the average field intake. The average intake opportunity time usually can be considered as the average of the opportunity times at the upper and lower ends of the field. If the rate of advance has been determined for separate reaches within the furrow length, a more exact weighted intake opportunity time can be computed.

Field Inflow-Outflow Method. The average field intake will equal the average depth of water retained on the field. In other words, it will be the average depth of water delivered onto the field (inflow) minus the average depth of surface runoff (outflow). Estimates of the depth of water put on the field are discussed in Step 2. In some cases surface runoff rates can be measured periodically in the drainage or waste water ditch to furnish adequate data for the computation of runoff volume and the average depth of runoff.

If site conditions do not permit adequate measurement of surface runoff rates, it may be possible to estimate the runoff from visual observations. When the average rate of flow into the furrows (total flow divided by the number of furrows) is known, it usually is possible to make a reasonable estimate

of the portion or percentage running off. Sometimes it may be possible to make measurements of runoff rates from representative individual furrows as an aid in estimating total runoff.

The inflow-outflow method of determining average field intake usually will be more accurate than the intake rate method. However, the inflow-outflow method is more time consuming. It usually requires outflow measurements at intervals throughout the runoff period.

Step 5.

Determine how well the water is spreading laterally between furrows. Near the end of the irrigation period, excavate a trench at right angles to the furrows or make an examination with a soil auger to determine the shape and position of the wetting front. Usually the entire ground surface need not be wetting front. Usually the entire ground surface need not be wetted ("blacked out") but the wetted bulbs from adjacent furrows should touch, or nearly touch, at their widest point. Very little lateral spread can be expected after the water is turned off. Most of the moisture movement or soil drainage after the irrigation is completed will be in a verticle direction.

Where cultivated row crops are irrigated by the furrow method, the furrow spacing usually is fixed. On these fields irrigation must be continued until an adequate lateral spread of water has been obtained—even if the extended time results in some additional deep percolation losses. The spacing of corrugations, however, is not so rigidly fixed. Usually they can be spaced so that an adequate lateral spread will have been obtained by the time the desired amount of water has been infiltrated into the soil.

Sample Analysis

Assume an evaluation is to be made of the irrigation of a field of sugar beets grown on a medium-textured soil.

Step 1.

The available moisture holding capacity of the soil was estimated to be 2.0 inches per foot. Auger holes were drilled and the soil moisture requirements were estimated as shown below.

TABLE I

Depth feet	Available Moisture percent	Available Moisture inches	Needed inches
0-1	25	0.5	1.5
1-2	50	1.0	1.0
2-3	75	1.5	0.5
3-4	100	2.0	0.0
Total		5.0	3.0

The beets were about 14 inches high and had been irrigated 12 days previously. The indicated average daily rate of consumptive use (1/4 inch per day) was estimated to be about right for the stage of growth and the weather conditions since the last irrigation.

Step 2.

The farmer said he was irrigating for 12 hours, using the total flow from a well that had a rated discharge of 675 g.p.m. The water was being run into 70 furrows, and the furrow spacing was found to be 36 inches. The length of the field was 660 feet. The average depth of application was computed as follows:

675 gpm = 1.5 cfs = 1.5 acre-inches per hour

1.5 x 12 = 18 acre-inches

70 furrows at 3.0 feet = 210 feet

(210 x 660) ÷ 43,560 = 3.18 acres

18.0 ÷ 3.18 = 5.67 inches average depth.

Step 3.

The farmer said the water reached the lower end of the run in about two hours. 2/12 = 1/6 of the total application time. No evidence of erosion was observed, but it appeared that the furrow streams were about as large as could be used safely. They averaged just under 10 gpm (675 ÷ 70 = 9.7 gpm).

Step 4.

The average depth of water infiltrated into the soil was estimated by the inflow-outflow method and from an intake rate measurement.

Inflow-outflow

Average depth of inflow (step 2) = 5.67 inches.

Outflow was measured and analyzed as follows:

TABLE II

Time after start of runoff: hours	Measured flow cfs.	Average flow cfs.	Time Interval hours	Volume ac. in.
0	0			
		0.225	1	0.225
1	0.45			
		0.525	2	1.050
3	0.60			
		0.625	1	0.625
4	0.65			
		0.700	3	2.100
7	0.75			
		0.785	3	2.255
10	0.82*			6.255

*Estimated.

6.255 ÷ 3.18 = 1.95 inches outflow

5.67 - 1.95 = 3.72 inches intake

Intake rate

Inflow-outflow measurements were made of three representative furrows. The measurements were made 9 hours after the start of irrigation. An average instantaneous furrow intake rate was determined from these measurements, and this furrow rate was used to estimate the field intake. The computations are shown below.

	Furrow number 1	2	3	
Inflow - gpm	10.1	9.0	9.3	
Outflow - gpm	5.6	4.4	4.3	
Intake rate - gpm	4.5	4.6	5.0	Average 4.7

4.7/6.6 = 0.714 gpm per 100 feet final furrow rate

0.714/3.0 = 0.238 inches per hour final field rate

0.238 x 1.33 = 0.316 inches per hour average field rate

The average intake opportunity time was considered to be 11 hours - 12 hours at the upper end of the field and 10 hours at the lower end. Average intake depth = 11 x 0.316 = 3.48 inches.

Step 5.

The water was diverted out of one furrow near the upper end of the run and a trench was excavated across this furrow to observe the water penetration pattern. It was found that the water had penetrated to a depth of 24 to 26 inches and had completely wet the area between furrows.

CONCLUSIONS

The field appeared to be receiving an adequate uniform irrigation. At the upper end of the field, where the intake opportunity time was 12 hours, the soil would absorb about 3-3/4 to 4 inches of water. At the lower end, with an intake opportunity time of 10 hours, the absorption would be about 3 to 3-1/2 inches. The average deep percolation loss would amount to about 1/2 to 3/4 inch.

Surface runoff appeared to be excessive. It amounted to an average depth of approximately 2 inches, or 35 percent of the water run onto the field. If the furrow inflow had been reduced shortly after the water reached the lower end of field, the runoff could have been reduced considerably. For example, if the streams had been cut back one-third 5 hours after the start of irrigation, the average depth of water applied would have been reduced to 4.57 inches.

1.5 cfs x 5 hours = 7.5 acre-inches

1.0 cfs x 7 hours = 7.0 acre-inches

Total = 14.5 acre-inches

14.5/3.18 acres = 4.57 inches.

This cut-back procedure would reduce the surface runoff loss by a half and would increase the overall field application efficiency from 53 percent to 66 percent.

$$3.0/5.67 = 53\% \quad 3.0/4.57 = 66\%$$

It might be possible to reduce the inflow streams earlier in the irrigation period to further reduce runoff losses and increase efficiency.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

CONTENTS

DISCUSSION

Page

Monthly Consumptive Use Requirements for Irrigated Crops, by Harry F. Blaney. (Proc. Paper 1963, March 1959. Prior Discussion: 2179. Discussion Closed.)
by Wayne D. Criddle and R. Keith Higginson 75
by Constantine P. Christopoulos 76
by Wendell C. Munson 78
by G. Marvin Litz 80

Drainage of Agricultural Lands Using Interceptor Lines, by W. W. Donnan. (Proc. Paper 1964, March, 1959. Prior Discussion: 2179. Discussion Closed.)
by A. R. Robinson 83
by R. H. Brooks 84

Economic Evaluation of Water, by P. H. McGauhey and Harry Erlich. (Proc. Paper 2059, June, 1959. Prior Discussion: none. Discussion Closed.)
by M. R. Lewis 89
by Robert O. Thomas 91
by S. T. Harding 94

Laboratory Research on Interceptor Drains, by Jack Keller and A. R. Robinson. (Proc. Paper 2154, September, 1959. Prior Discussion: none. Discussion open until February 1, 1960.)
by M. Maasland 97

Aquifer Tests in the Snake River Basalt, by W. C. Walton and J. W. Stewart. (Proc. Paper 2156, September, 1959. Prior Discussion: none. Discussion Open until February 1, 1960.)
by M. Maasland 101

Note: Paper 2327 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, IR 4, December, 1959.

Page

Drainage in the Coachella Valley of California, by Lowell O. Weeks. (Proc. Paper 2158, September, 1959. Prior Discussion: none. Discussion open until February 1, 1960.)
by M. Maasland 103

MONTHLY CONSUMPTIVE USE REQUIREMENTS FOR IRRIGATED CROPS[a]

Discussion by Wayne D. Criddle and R. Keith Higginson, Constantine P. Christopoulos, Wendell C. Munson, and G. Marvin Litz

WAYNE D. CRIDDLE,[1] M. ASCE and R. KEITH HIGGINSON,[2] A.M. ASCE.—Mr. Blaney has described the need for and the uses to which monthly and shorter period irrigation water use rates can be put. However, these kind of data are extremely difficult to attain and duplicate.

Consumptive uses and water requirements of crops are influenced not only by climatic factors but also by growth characteristics of a particular crop. Growth rates and resulting water consumption rates are also influenced by insect attacks on plants, on kinds, amounts and forms of fertilizer added and the stage of growth at which it is applied. Use of water depends to some extent upon the frequency of irrigation and the completeness with which the root zone of the crop is moistened. In general, crops under field conditions may grow in "spurts" dependent, to a great degree, on the combination of influencing factors being favorable for growth. Consumption of water by alfalfa will vary because of cutting and pasture use by grazing.

If the above be true, then we can expect wide variations in use rates during short periods of time. But the longer the period under consideration, the more nearly we should be able to predict what the use will be, based on readily available data such as climate.

Research studies to date seem to bear out this premise. We have been able to estimate full growing season use rates with reasonable accuracy, probably because crops usually grow to maturity by the end of the season and, in so doing, consume about the same quantities of water from year to year if climatic conditions are not too dissimilar.

Estimates of short time use rates seem to be highly erratic. Also, measurements of use show wide variations. Thus, any empirical formula for estimating short period, or monthly use rates, will come from a great number of actual tank, plot and field measurements which will show the magnitude and range of use rates under various catalogued conditions. Mr. Blaney has presented a number of monthly values. But, when carefully studied, they appear to have no particular pattern. The variations seem to be greater than one might expect from just climatic differences. Other influencing factors are not shown, nor can they be without a great amount of additional instrumentation and study.

From a practical standpoint, we may have to get along with our rough estimates for some time yet before we find out how to measure all influencing factors, and before the value of such information justifies the cost. In

a. Proc. Paper 1963, March, 1959 by Harry F. Blaney.

1. Civ. Engr., Salt Lake City, Utah.
2. Engr., State Engrs. Office, Salt Lake City, Utah.

other words, we may have to be satisfied with what data we are getting on consumptive use of water rates until we are willing to pay the cost of the added data. To be of maximum value, we must also be able to predict what all these influencing factors will be under field conditions and use the data accordingly.

CONSTANTINE P. CHRISTOPOULOS.[1]—To finding a way of forecasting irrigation water requirements of crop plants, Mr. Blaney has been delving amongst the many climatologic, biologic and other factors which determine the quantity of water that is consumed by plants under optimum soil moisture conditions for their growth and by evaporation from the adjacent soil.

The paper under discussion is the latest contribution of Mr. Blaney to irrigation and hydrology literature. In the centigrade scale of temperature and in millimeters the original Blaney-Criddle formula for computing evapotranspiration from climatologic data is:

$$U = KF = \sum kf = \sum kp\,(8 + 0.45\,t) \qquad (1)$$

This formula has had a great success and it is used throughout the world. This success may be largely attributed to the "climatic factor" (f) being easily determined from data of mean monthly temperature (t) and monthly daytime percentage (p) that are everywhere at hand. In contrast, other relevant formulas, simple or complicated, are based on climatological data that are not usually available or they must be measured with elaborate and delicate equipment.

This writer for years has been using the Blaney-Criddle formula, and in a few instances he has verified its accuracy for computing the seasonal amounts of evapotranspiration. But regarding the accuracy of the monthly quantities of consumptive use given by the original Blaney-Criddle formula and all other similar formulas, there was much doubt; for while the plant magnitude is variable with time, the seasonal "plant factor" (K) is considered as constant throughout the growing season and the life of plant.

With the paper under discussion presenting a number of "monthly plant coefficients" ($k = \frac{u}{f}$), thus eliminating the constancy of the "seasonal" (K), Mr. Blaney offers one more great service to irrigation and hydrology science. However, it would be highly desirable for many other such monthly coefficients (k), "plant" or "biologic" factors, to become known. Presently this is only possible in the United States, where monthly measurements of consumptive use for nearly all the irrigated crops and some other native plants are being made by the Federal Agricultural Research Service, State Experiment Stations and other agencies.

Another point that requires further investigation is the maximum deviations of the monthly quantities of consumptive use from their averages, to which all the formulas of evapotranspiration are confined. This writer has found in a certain case that such deviations of temperature and humidity during the critical months of July and August reached maxima (concurring to larger exapotranspiration) of 15% at an average in the area of the case.

Of course, it is to be understood that forecasting with accuracy averages, and deviations therefrom of evapotranspiration quantities is by no means an

1. Prof. of Hydr. Eng., University of Thessaloniki, Salonika, Greece.

easy matter. Such quantities (U) are very complex functions of many variables, of which more important are temperature (Te); sunlight (Sl); length of growing season (Gs); humidity (Hu); wind movement (Wm); species (probably) and size of plant (Ps), that may be expressed by the following equation:

$$U = \phi\,(Te, Sl, Hu, Wm, Gs, Ps, \ldots .) \qquad (2)$$

What one should reasonably expect as a result from such a complex function is an approximation adequate for the practice and consistent with the degree of accuracy of other quantities entering the problems of irrigation, hydrology and engineering in general.

Mr. Blaney's method for solution of such a complex problem, as this method is now presented by the paper under discussion and as it may be supplemented with additional (k) values, contains in the simplest possible form the most important (and permanent in a locality and available anywhere) elements of the function in equation (2); that is, Te, Sl and Gs for Climate and Ps for plant species and size. Obviously for reasons of simplicity, it omits Hu and Wm, which are much less significant and often not well known.

In this way Mr. Blaney offers a service to irrigationists and hydrologists.

Besides, mathematically exact computations of evapotranspirations, if they were possible at all, would be of very doubtful usefulness, as far at least as forecasting irrigation water requirements and scheduling irrigation water distributions are concerned.

What is much more significant than exact forecastings with reference to irrigation in our days is an Irrigation Practice that would take full advantage of the large amount of irrigation knowledge that American engineers are every day gathering from the beginning of the 20th century. The well-known revolution of American engineers in the field of irrigation has not as yet been as fruitful as it could be. Between the well-established irrigation principles (on such fundamental subjects as the relations of soil-water-plant, the evapotranspiration and other alike questions) and the irrigation practice, there is a wide gap.

This gap between irrigation principles and irrigation practice is exampli-fied by the farm irrigation efficiency—

$$\frac{\text{Consumptive use of water by plants}}{\text{Water applied for irrigating plants.}}$$

This ratio is prevailingly and at best from 0,40 to 0,70 instead of unity, to which it should and could approach much more. What's the use of knowing exactly the true needs of plants for water when we apply to lands wastefully and harmfully much more?

Finally, Blaney's method for computing monthly evapotranspiration, together with the findings of other American engineers and scientists about the relationships of soil-water-plant and other relevant subjects should constitute the basis of a systematic endeavor for such a rationalization of irrigation practice as it may be consistent with economy of water, labor and money. And this depends largely upon methods of delivering and of applying water to lands.

As irrigation agriculture promises to become a blessing for all mankind and large irrigation projects are under construction all over the world, the aim of bringing irrigation practice in line with well-established irrigation principles is worthy of the attention of Americans who lead the way in irrigation investigations.

WENDELL C. MUNSON,[1] F. ASCE.—"Results of monthly determinations of evapotranspiration and transpiration for irrigated crops may be employed to plan irrigation schedules and for estimating water requirements for each crop for maximum production," so states Mr. Blaney. The writer emphatically agrees with this statement. Mr. Blaney then goes on to state, "The importance of a knowledge of water lost through evaporation and consumptive use to the efficient design and later operation of the works involved in a water-supply project has long been recognized by engineers." The writer concurs wholeheartedly with this statement also. However, the methods presently used by various investigators in making the transition from statement number one to statement number two present an area of disagreement to the writer. The transition from the plot to the project must consider a myriad of intricate and inherent factors of great import. A few of these are:

Variety of individual crop
Cropping practices
Quality of water
Homogeneity of project soils
Harvesting methods
Homogeneity of ground-water conditions
Drainage conditions
Within project climatic variations
Infiltration rates of various project soils
Soil treatment methods

For example, Mr. Blaney in Table 7 shows a consumptive use of 51.0 inches of water for alfalfa at Mesa, Arizona. Is this the amount of water required for a certain particular strain? Will this amount of water produce 2 tons per acre or 5 tons per acre? How much variation will there be in yield under different planting methods, different harvesting methods, different water table conditions, and so forth, and so forth? Assuming all these conditions to be known as well as the first year's cropping pattern, what assurance do we have that this certain pattern will continue on this project? If we have 1,000 acres planted to alfalfa, what assurance do we have that the requirement will apply equally to each acre in the field? These are but a few of the many unanswered or unanswerable questions. Because of the great amount of time involved to attempt to compute the influence of these many factors, the writer some years ago devised a simple, rapid method for computing the estimated project consumptive use which he believes has sufficient accuracy to warrant its use in project formulation.

During the 1930's, Mr. C. W. Thornthwaite developed a formula which he used to classify climate. For every station where monthly observations of precipitation and temperature have been made, it is possible to compute the P-E ratio and the P-E index, which thus become an evaluation of the effectiveness of precipitation. The quotient P/E is called the P-E ratio and the sum of twelve monthly P-E ratios is called the P-E index. Mr. Thornthwaite developed a nomogram by which he was able to read the P-E ratios directly when the average monthly precipitation and temperatures were known.

During the early 1940's, the writer found that crop yields followed a pattern paralleling the P-E indexes. It was also apparent that if the monthly P-E

1. Hydr. Eng., Bureau of Reclamation, Wash. 25, D. C.

indexes. It was also apparent that if the monthly P-E ratios approximated 48 that crop production was adequate with the normal rainfall of eastern Nebraska and western Iowa. Subsequently, many weather stations over the Missouri Basin and Western Iowa were studied and a set of representative monthly P-E ratios determined. Then by using the average monthly temperatures and the assumed P-E ratios, it was just a matter of reading from the Thornthwaite nomogram to readily determine the required precipitation, or consumptive use requirement, for crop production on an area basis. After some years of study of weather and crop data from irrigated areas over the western United States, the writer arrived at a set of P-E ratios which were adequate for normal plant growth at any of the many stations studied. They are:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.0	1.8	3.2	4.4	5.8	6.0	6.8	6.1	4.6	3.5	2.3	1.5

Annual
47.0

To determine project consumptive use, it is necessary only to ascertain the average monthly temperatures at a representative weather station, then apply a straight-edge at the desired monthly P-E ratio and the average monthly temperature for the desired month and read directly, the necessary consumptive use. Later, a tabulation was prepared to facilitate this process.

The method is accurate, rapid, and simple. It gives the monthly and annual requirements directly. As is the case with any theoretical formulae, it is necessary to exercise judgment in the use of this method. Additional refinement will doubtlessly be necessary, and experience may show that the assumed P-E ratios will require some adjustment to adapt them to peculiar conditions in some areas. However, for project planning where cropping practices are estimated, farm efficiencies are estimated, canal and lateral seepage are estimated, and future operators' idiosyncracies are indeterminate, it appears that adoption of such a simple, rapid, and reasonable accurate method of estimating relative consumptive use, such as the P-E index method, should be given serious consideration.

Although the writer has not attempted to convert this generalized project requirement to individual crops, it could probably be done. Average project conditions over the areas studied represent an overall crop density of some 60 percent, allowing for idle lands, buildings, and average planting densities. Therefore, to convert to alfalfa, for example, all that would be necessary would be to apply the 60 percent factor, assuming alfalfa to be 100 percent density. Thus, Mr. Blaney's Table 7 results as compared to the P-E method would be as follows:

Month	Temperature	P-E Req. 1/	Adjusted 2/	Requirement
January	48.3	0.54	0.90	1.0
February	51.9	1.00	1.67	2.0
March	56.9	1.86	3.10	3.5
April	67.3	3.05	5.08	5.0
May	73.6	4.31	7.18	6.5
June	82.1	5.07	8.45	9.0
July	89.3	6.23	10.38	12.0
Sept. 15-30	82.6	2.00	3.33	3.0
October	68.6	2.53	4.22	4.0
November	54.7	1.32	2.20	3.0
December	50.6	0.83	1.38	2.0
Totals			47.89	51.0

1/ Read directly from table
2/ P-E Requirement divided by 60%

G. MARVIN LITZ,[1] M. ASCE.—The monthly consumptive use data presented by Mr. Blaney fill a need in many areas for use in the solution of varied water problems. Each specific water supply problem points out additional land use classifications for which consumptive use data are lacking.

When only a crop, its growing period and its growing period consumptive use coefficient (K) are available, it is sometimes desirable to estimate monthly consumptive use coefficients (k) based upon mean monthly consumptive use factors (f). The method shown below, which follows from the nature of Mr. Blaney's equation and its development,(1) has been found useful.

Briefly, the method involves the calculation and use of an additional constant (A) which is the summation of the squares of the monthly consumptive use factors (f) for the growing period, divided by the calculated growing period consumptive use (U).

The monthly coefficients (k) are calculated from the relation $k = f/A$. Also, monthly consumptive use (u) can be calculated from either of the relations; $u = k\,f$ or $u = f^2/A$.

In the following example it was assumed there was a need for the monthly consumptive use values for rice at Mesa, Arizona for the years 1945-1946 and an April through July growing period. The growing period consumptive use coefficient (K) of 1.20 was selected from Table 5, and the monthly factors (f) were taken from Table 7.

The growing period consumptive use (U) = K F = 1.20 x 29.77 = 35.72.

The constant (A) = (summation f^2) / U = 226.06 / 35.72 = 6.33.

Each monthly coefficient (k) was calculated by dividing the monthly factor (f) by 6.33. The monthly consumptive use values (u) were obtained by dividing the monthly factor squared (f^2) by 6.33.

1. Civ. Engr. Assoc., Dept. Water and Power, City of Los Angeles, Los Angeles, Calif.

Example: Preliminary estimates of monthly consumptive use coefficients and consumptive use of rice based upon monthly consumptive use factors for Mesa, Arizona, average of 1945-1946.

Consumptive Use

Month	Factor (f)	Factor^2 (f^2)	Coefficient (k)	Inches (u)
April	5.92	35.05	.94	5.53
May	7.13	50.84	1.13	8.04
June	7.92	62.73	1.25	9.92
July	8.80	77.44	1.39	12.23
Total	29.77	226.06	----	35.72

REFERENCES

1. Consumptive Use of Water, by Harry F. Blaney, ASCE. Trans. Vol. 117, p. 949, 1952.

DRAINAGE OF AGRICULTURAL LANDS USING INTERCEPTOR LINES[a]

Discussion by A. R. Robinson and R. H. Brooks

A. R. ROBINSON,[1] M. ASCE.—The paper by Mr. Donnan deals with an important phase of drainage design. In the Western United States, interception drainage of agricultural lands is being used to a large extent. It has been estimated that about 90 percent of the drain installations in the state of Colorado are of this type. With the interceptor drain, a portion of the seepage flow is cut off and removed with the result that the ground water level is lowered so that agricultural production may be restored or maintained. This paper represents a significant contribution of information for the design of such drains.

Developments of this type usually contain assumptions which although necessary may limit the usefulness. Some of the assumptions which were stated or implied were: (1) steady state conditions, (2) uniform conductivity or permeability, (3) a uniform sloping bed of relatively impermeable material, and (4) the source of the seepage flow at infinite distance from the proposed location of the drain line. The assumption of a steady state condition is one which may have serious implications in determining the position of the water table, particularly so if frequent applications of irrigation water are made in the area. However, the addition of the time variable into the problem has resulted in a relationship for which no solution has yet been determined. Non-uniform permeability or an impermeable boundary which does not have a uniform slope would result in a drawdown curve which is not a smooth curve such as that shown in figure 4. The source of ground water may, in some cases, be near the location of the drain line. This would be the case of an interceptor installed near a canal or reservoir to cut off the seepage which is occurring.

The statement is made by Donnan that equation 5 gives infinite values of x. This is true only when the slope of the boundary is equal to zero or when the y coordinate of the drawdown curve is equal to the undisturbed depth H. Actually the slope of the undisturbed water table can be used rather than that of lower boundary and this value must always be greater than zero if flow is occurring. The value of y will always be less than H except at the point where the drawdown curve becomes asymptotic to the original water table. For this case, that point is at an infinite distance. Equation 5 can be used directly to determine the x coordinate for any depth y which is less than H. Solving equation 5 for the example given by Donnan results in a distance of 545 feet rather than 600 as was determined by the approximation method. A

a. Proc. Paper 1964, March, 1959 by W. W. Donnan.

1. Agri. Eng. Western Soil and Water Management Research Branch, U. S. Dept. of Agriculture, Agri. Research Service, and Colorado Agri. Experiment Station, Fort Collins, Colo.

nomograph for the easy solution of equation 5 has been prepared and will be appended to a forthcoming publication as part of the discussion.(1)

A large scale model study(1) was made to determine the validity and limitations in using equation 5. From this study it was determined that equation 5 was usable under the imposed conditions. However, in the case of interception of flow from a source such as a nearby canal, there was a large deviation in the position of the water table as determined by equation 5 and that actually observed. For this case a procedure is outlined for determining the correct position of the water table.

In the discussion by Donnan of the amount of flow intercepted by drains placed in different positions relative to depth of saturated flow, the statement is made that the percentage of flow removed is approximately equal to the ratio of depth of flow intercepted to the total depth of undisturbed saturated flow. This is true for only the isolated case of flow from a source of constant magnitude and at an infinite distance from the drain. Again using the nearby canal as an example, it was shown(1) that the flow may be increased so that the intercepted flow is much greater than the original flow before the drain was constructed. This is as a result of a steeper gradient and the presence of the nearby source which is not constant but may increase as the gradient is increased.

The statement is made that the interceptor drain is usually installed to protect the land on the downslope side. This is certainly true and actually means that the determination of the upstream water table shape is of secondary importance with the downstream one being of primary interest. Contrary to the statement that the downstream water table approaches a lower position beginning with the height of the water surface in the drain, it can be shown both analytically and by model studies that this is not the case. The shape and position of the flow and equipotential lines in the vicinity of the drain also indicate that the water table downslope will rise to an elevation greater than that in the drain. For certain cases this rise may be appreciable. A considerable amount of study is needed in this important area.

REFERENCE

1. Keller, Jack and Robinson, A. R. Laboratory Research on Interceptor Drains. To be published as a Proceedings Paper by ASCE in the Journal of the Irrigation and Drainage Division.

R. H. BROOKS.[1]—The author is to be complimented in bringing forth Glover's steady state solution for the interceptor drain problem. This solution will be helpful in designing drainage systems where the upstream position of the water table is of primary importance. The solution is based upon the horizontal flow assumptions of Dupuit and, as the author has indicated, it does not apply in the immediate vicinity of the drain.

Mr. Donnan's discussion of the "drawdown downslope" from the drain needs some comment. An analysis of the system using Laplace's equation is in contradiction with some of Mr. Donnan's statements in this section. These

1. Agri. Engr. Western Soil and Water Management Research Branch, Soil and Water Conservation Research Div., Agri. Research Service, U. S. Dept. of Agriculture, Fort Collins, Colo.

contradictions are no doubt due to the assumption that the flow is considered parallel to the impermeable boundary. This assumption is in serious conflict with the real system and may lead to erroneous concepts concerning the shape and position of the downstream water table.

The same geometry, symbols and boundaries as shown in Mr. Donnan's figure 4 will be used in this discussion except consider the slope of the impermeable boundary, α, to be to the right such that a right hand cartesian coordinate system may be used. The shape of the water table throughout the system may be qualitatively deduced by analyzing the velocity along the water table. For this analysis, it is convenient to use functions of a complex variable. It can be shown[1,2] that the equation which describes the direction and magnitude of the velocity vector as it traverses the water table is given as:

$$(Vx - \frac{K \text{ Sin } \alpha}{2})^2 + (-Vy - \frac{K \text{ Cos } \alpha}{2})^2 = (\frac{K}{2})^2$$

where Vx and Vy are the velocity components along the water table in the x and y directions, α is the angle of the inclined impermeable layer with the horizontal, and K is the hydraulic conductivity of the porous media. This equation represents a circle of radius K/2 which passes through the origin with its center at K/2 Sin α and -K/2 Cos α as shown in figure 1.

A vector, V, with its tail at the origin and its head on the circle represents the magnitude and direction of the velocity along the water table. The curve which this vector describes is referred to as a hodograph. From analyzing the velocity components, Vx and Vy, of the velocity vector, V, on the circle, the shape of the free surface may be qualitatively drawn for the geometry and boundaries given. The origin of the hodograph is a point in the actual flow region where the velocity is zero. It should be noticed that every point on the circle represents a finite velocity on the water table throughout the flow region. Let the actual flow region be designated the Z-plane, and the velocity vectors on the circle in figure 1 be designated the W-plane or hodograph.

The point A in the W-plane corresponds to a point at an infinite distance upstream from the tile in the Z-plane where the velocity is proportional to the slope of the impermeable boundary. The magnitude of this velocity is K Sin α. As one proceeds around the circle in a clockwise direction from A, the y component of velocity increases in a negative direction. Thus, the water table must be drawn down toward the drain. At B in the W-plane, Vy is near its maximum value and Vx is zero. This point corresponds to a point in the Z-plane where Vx on the water table changes from a positive to a negative direction. To satisfy this condition point B must be near the tile since Vy is near a maximum and it must be downstream from the tile since Vx must reverse its direction. At point C, both Vx and Vy are zero which is termed a stagnation point. Also at point C, Vx and Vy change direction and are both directed positively upward. This implies that the water table must climb upward and approach asymptotically a line parallel to the impermeable boundary. At point D, the velocity is again proportional to the slope of the impermeable boundary. As shown in the W-plane, the magnitude of the upward component of velocity from C-D is related to the slope of the impermeable boundary and the hydraulic conductivity.

The shape of the water table has been qualitatively drawn in figure 2 from the analysis made in the W-plane. Laboratory and model studies by this author in the immediate vicinity of the interceptor drain have corroborated this analysis.

In most instances, the depth of the water table downstream from the tile drain is the most important factor in the design of interceptor tile drains. Since the water table rise is greater than the elevation of the drain above the impermeable boundary, it is very important to be able to determine the magnitude of the water table height for a given depth of tile drain. Serious error may result in assuming that the depth of the water table downstream from the tile drain remains at a distance equal to the height of the drain device above the impermeable layer. The magnitude of the error involved cannot be determined until the problem has been solved using Laplace's equation. However, when considering the proper depth of tile drains, it should be recognized that a water table rise does exist below the drain.

The statement is made by Mr. Donnan that "some water may escape out of the drain device itself on the downslope side." This is physically impossible if the water table takes the shape and position as shown in figure 2. The

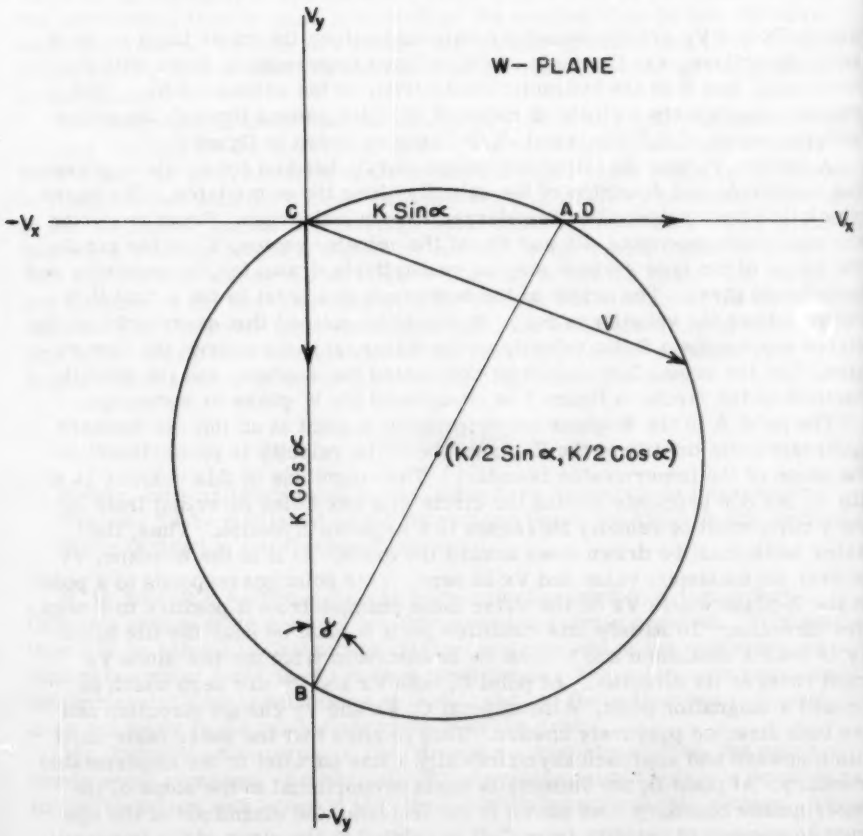


FIGURE 1. HODOGRAPH CORRESPONDING TO FLOW IN THE Z-PLANE

drain acts as a sink and flow is toward the sink around its entire circumference.

REFERENCES

1. Smith, L. P. Mathematical Methods for Scientists and Engineers. Prentice Hall, New York, 1953.

2. Van Schilfgaarde, Jan; Kirkman, Don; and Frevert, R. K. Physical and Mathematical Theories of Tile and Ditch Drainage and Their Usefulness in Design. Research Bul. 436, Agricultural Experiment Station, Iowa State College. 1956.

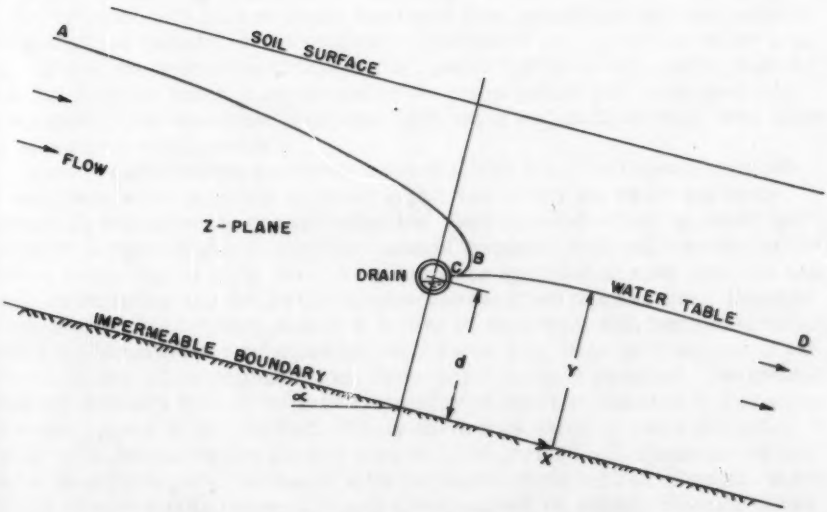


FIGURE 2. WATER TABLE SHAPE FOR INTERCEPTOR DRAIN

ECONOMIC EVALUATION OF WATER[a]

Discussion by M. R. Lewis, Robert O. Thomas and S. T. Harding

M. R. LEWIS,[1] F. ASCE.—The paper does not attempt to determine the value of water but, rather, questions the historic attitude that irrigation is the prime use to which water in the arid and semi-arid sections of the country should be put and purports to show that industrial use provides much higher economic values. This thesis, as distinguished from the formal title of the paper, only recently has been given serious consideration in spite of its great and growing importance. Its neglect heretofore has been chiefly due to the fact that only in rare cases has there been actual competition between irrigation and industry in the original allocation of any particular water supply. There has been competition in the case of hydroelectric power production but since no water is consumed in the power plants and these generally are located upstream from irrigation diversions the conflicts have been more or less easily compromised.

In many cases where domestic, municipal and industrial needs have outgrown their water supplies or water rights and irrigation water has been physically available the needed water has been obtained either by direct purchase of irrigation water or by purchase of irrigated land and transfer of the water; depending on state laws. In either case approval of state officials has been forthcoming and the irrigated area has reverted to other use. Usually these transfers have been simply a matter of negotition with individual water users but sometimes condemnation procedures have been used and, as in the Owens Valley - Los Angeles case, bitter quarrels have resulted. Nevertheless the author's fear of the irretrievability of water committed to irrigation does not appear to be justified. Where the money value of water for industrial or municipal use is greater than it is for irrigation, adjustment seems to be feasible enough. In cases, such as the recreational use of water, where social or community values although great can not be readily be ascertained in monetary terms, the problem is much more difficult.

The author's review of the history of irrigation development in the United States is essentially correct. At present when huge surpluses of different crops are much in the public mind it is easy to forget that in many parts of the world today and, quite possibly, in America tomorrow food production is or will be the basic need with first call on water.

The figures given in the paper as to the suitability of California land for irrigation are deceiving because both classifications reported in tables 1 and 2 disregard the possibility of irrigation. In the Soil Conservation Survey

a. Proc. Paper 2059, June, 1959, by P. H. McGauhey and Harry Erlich.
1. Associate, Carroll E. Bradberry and Associates, Consulting Engineers, Los Altos, Calif.

reported in Table 1 and shown on the map, Fig. 4, large areas were classified as unsuitable for cultivation because no irrigation water supply was obvious at the time of the survey. Since then the California Water Plan has been completed and contemplates the irrigation of much of this type of land, particularly in Kern, Los Angeles and San Bernardino counties. The report of the National Resources Board, from which the data of Table 2 are drawn, states that, "Irrigated lands were graded according to their original non-irrigated condition ----." Obviously no desert lands are productive without irrigation. California's record in agricultural production appears to be ample proof that 93 to 99.5 per cent of its lands are not third class or worse. As a matter of fact the National Resources Board in 1936 estimated the ultimate irrigable area in California as 16,673,000 acres.(1)

While comparisons of the quantity of water used in irrigation and in industry with the production of wealth, taxes, income and employment in farming and in manufacturing may be indicative of the relative values of water in the two cases, figures developed by the author are certainly no more than that. In irrigation farming water is always a primary requisite and an important cost element whereas in many manufacturing enterprises the use and value of water are of negligible importance. For this reason the use of industry-wide monetary returns from manufacturing as a measure of the comparative value of water in industry and in agriculture is unreasonable. Estimating the value of coal or petroleum by comparing their use as fuel and the returns therefrom with their use as sources of chemical derivatives with the returns to the whole chemical industry would be just as valid.

An extended investigation in great detail would give a reasonable evaluation of the comparative value of water in particular industries but questions arise. Much water is used in industry for cooling and condensing in such manner that neither its quality nor its quantity is greatly changed. In some processes the quality of the water used is so degraded by waste products that it can be reused only after expensive treatment. Still other uses result in almost complete consumption of the water by evaporation. Any or all of these results will be found in a study of almost any water use. Even within a single industry the uses are sometimes very different. It has been reported that the use of water at the Fontana Plant of the Kaiser Steel company is roughly one-fiftieth of that used at other steel plants for the same production.(2)

There is no easy or general formula by which the value of water can be determined. The orthodox economists' reliance on the open market to fix the value by give and take between buyer and seller will not serve since there is no open market. Both the cost of production and the price that would be paid if necessary range so widely as to have no meaningful median or average or what-have-you value. Hines(3) discusses the difficulties of determining the social values of use of water and the social costs of misuse.

There are numerous arithmetical discrepancies within and between the tables in the paper but since the relations between the data and the conclusions are so nebulous exact values are of little interest.

Certainly the value of water put to different uses varies tremendously and this does have great bearing on the development of water resources especially in areas of deficiency. It is unfortunate that the present paper is not more realistic in its treatment of the subject.

REFERENCES

1. Irrigation Agriculture in the West, U. S. Dept. Agr., Misc. Pub. 670, Nov. 1948, p 9.
2. Woodward, Douglas R. in Discussion of, "Water a Limiting Resource," Proc. Paper 1754, 1959.
3. Hines, Lawrence G., Water Resources - Problems in the Analysis of Development and Use in the United States, Jr. Soil and Water Conservation 14:160-164, 1959.

ROBERT O. THOMAS,[1] ASCE.—The appearance of this paper in a technical journal is a further manifestation of the growing interest of the engineer in the social and economic implications of his activities. These latter aspects of development are becoming important due to the increasing cost of meeting the accelerating demand for water supplies for beneficial uses. At the same time, the engineer must exercise due caution to protect the economy from the impact of jarring dislocations. Exercising, as he does, the over-all responsibility for planning, designing, constructing, and operating water resource development projects, he must control and direct the application of allied doctrines and disciplines to his plans.

Water rights, under our legal system, are a form of property and due process must be followed in effecting changes in ownership or control. In general, they consist of two types; riparian, or those rights associated with the location of real property; and appropriative, or those associated with a particular use at a particular location. Particularly as concerns the United States, the legal principles governing and controlling property rights have been developed over the course of hundreds of years by the courts of the Anglo-Saxon countries. These principles cannot be arbitrarily discarded as uncharitable simply because they cannot be reconciled with new, and unproved, theories of "welfare economics" and "planned economy." The writer knows of no instances wherein a water right has been held to affect, or limit, the price of water at the point of delivery. Likewise, there appears to be no justification for depriving an individual of a vested right in a species of property on the theory that some other person would be willing to pay a greater sum for the same, or a similar commodity. While it is true that, in the original instance, the factor of price may have a decided influence in the decision to acquire, or not to acquire, a specific property, it becomes a nullity after purchase has been accomplished. An indictment of water rights, therefore, as an element in advocating an open market price system, is somewhat indefensible.

The usual theory of resource allocation requires that the available supply of the resource be either theoretically, or practically, limited. This may be true in relation to the supply of certain minerals. Since the amount is limited, the time of total depletion, when the human race will necessarily be required to develop substitutes, may be foreseen. Consequently, the principle of allocating such scarce, limited resources to the uses resulting in maximum economic gain during the time they are available, is a commendable objective. Water does not appear, at least at present, to be such a resource. Water may

1. Superv. Hydr. Engr., State Dept. of Water Resources, Sacramento, Calif.

be scarce in the sense of temporary availability or of maldistribution, but the supply is continually renewed. Consequently, an allocation system wherein the available quantity of a continually diminishing, non-renewable resource is channeled into the processes or uses resulting in maximum economic, or monetary, gain is unnecessary.

The open market, or auction, pricing system for commodities is quite generally illustrated by reference to a rigidly controlled economic system wherein the supply made available is related to the price obtained as a result of demand. A limited quantity will command a high price, while gradually increasing availability results in lowered prices. At some point in the scale, maximum return will be secured, and that quantity and price will become "the market." The ability to withhold the article, or commodity, from the market in order to maintain price is implicit in this concept.

Water, however, enters into almost all aspects of human life and endeavor. Its utility and value in enabling the fulfillment of human wants and desires may be governed by different standards at different times and places. The quantity of water, for instance, required to produce a crop of alfalfa for cattle feed may also produce many tons of steel. The price received for meat, however, will, in turn, govern the price of cattle at the stockyard, and of feed, and will affect the price at which water can be sold for the purpose of raising feed. At the same time, the human race requires food in order to survive.

On the other hand, the price of water sold to a steel mill is, in all probability, a minute portion of the price per ton of the finished product. An increase of 100 per cent in cost of water might result in an increase of only a few cents in the price of the end product. Usually this would be an extremely small percentage. Since the arguments against a lower price for agricultural water supplies are usually directed to pricing based upon the ability of the farmer to pay from income received, it might be well to study the reverse aspect of the matter. If the farmer is to compete with the industrialist for water, then either farm income must be raised, thereby projecting tremendous increases in the cost of food to the consumer; or the pricing to the industrialist might also be based upon ability to pay, in which event the price of water for urban consumption should probably be raised to a level far above its current standard. It has become fashionable, of late, to decry "subsidization" of agriculture. A discussion of "ability to pay," however, leads to the interesting question, "whom is subsidizing whom?"

The writer is definitely of the opinion that the economic evaluation of water and the price at which it is offered for sale must be related, in each separate case, to the quantity concerned, the use proposed, the place of use, the result in satisfaction of human needs and desires—and the very real, practical consideration of source and amount of available funds to finance the purchase. The price may be, and often is, considerably at variance with the cost of furnishing the supply. Such disparity is closely related to overall policy, in the case of governmental agencies, and has only a remote relationship to the economic value of the commodity or service furnished. An outstanding example of the latter is the governmental postal service.

The author has severely criticized the finding of California state agencies to the effect that approximately 20,000,000 acres of land in that State are suitable for the development of irrigated agriculture. As proof of basic errors, he cites a Soil Conservation Service two-year reconnaissance survey, and a 1934 estimate of the former National Resources Planning Board. In

actuality, the federal reconnaissance finding of 16.5 million irrigable acres is not greatly at variance with the state determination of 20 million, when varying standards, particularly in desert areas, are taken into account. It will be noted that the federal survey classifies desert land in the immediate vicinity of existing development as suitable for cultivation, while similar land at a distance is not so classified. It will also be noted that the Owens Valley, a formerly irrigated area, is classified by the SCS as unsuitable. The sole reason for discontinuing irrigation and agricultural productivity was the purchase of rights and lands by the City of Los Angeles for the development of a municipal supply. It appears to the writer that the SCS classification was highly influenced by the ready availability of a water supply. The state study, on the other hand, was solely concerned with the physical attributes of the land itself.

The author states, unequivocally, that land classification has not had a great deal of weight in the justification of water resource development. It is then stated that without land classification criteria, water deficiency is used as the excuse for supplying water to the land. The writer is impelled to take direct issue with these statements. In the first place, the major federal water development which has occurred in California has been for the principal benefit of lands already developed to agriculture in one of the richest farming areas in the United States. Much of the development was based on development of ground water and falling water tables made it imperative to develop alternate sources of water or face economic disintegration.

In the second place, it appears that the author's criticism is specifically directed at The California Water Plan. In fairness to the water planning agency which prepared the Plan, it must be stated:

1. The Plan is a master plan setting forth the manner in which water could be developed when, as, and if the need occurs.

2. It demonstrates the capability of the State's water resources to meet forseeable requirements, insofar as they can be determined or estimated at this time.

3. The Plan is not "justified" as a whole. Each of the approximately 300 individual projects included will be studied and justified on the basis of engineering, financial feasiblity, and economics at the time when that project is actually proposed to be built.

4. Insofar as present estimates of future needs are concerned, the Plan provides for a 100 per cent increase in present (1950) irrigation use and a 500 per cent increase in present (1950) urban water use. This can hardly be described as neglecting urban requirements.

5. It has been officially stated, many times over, that the Plan will be revised and amended in accordance with the development of California's economy.

Consequently, it may be seen that The California Water Plan is solely that which it purports to be—a flexible master plan, demonstrating that the water resources of the State are ample to provide for the forseeable ultimate needs and providing for the construction and integration of future developments in accordance with the water requirements and financial and economic standards existent at that time.

The paper has emphasized the greater financial returns, employment

opportunities, and general economic growth ordinarily associated with urban and industrial growth as opposed to agriculture. This may be true in the abstract, but in practice there is no such sharp line of demarcation along which opposing battle lines are drawn. In a region with an exceptionally high agricultural development, such as California, one must bear in mind the close inter-relationship between agricultural and urban economies. The data quoted in the paper would have been much more meaningful if that part of the urban economy consisting of food and fiber processing; fertilizers; pipe and pump manufacturing; agricultural implements; agricultural sales and marketing; transportation of foodstuffs and agricultural supplies; etc., etc., had been shown separated from other urban statistics. The question may well be asked, "If primary agriculture (farms and farm employment) were to be removed from California's economy today, how much of the remaining economy would collapse with it?" It is popular to decry the place of agriculture in the general scheme of things as they are, but with the broad exceptions of the petroleum, aircraft, and electronic industries, it can well be argued that agriculture supports a far greater segment of the economy that that represented by the 6 per cent of total income and less than 10 per cent of employment attributable to that field of endeavor.

Regardless of the writer's disagreement with the conclusions as expressed in the paper, the opening of this field for widespread discussion by those intimately associated with the problems of water development, transportation and use can only have a salutary result on future project investigation and planning.

S. T. HARDING,[1] F. ASCE.—In this paper the authors have presented a good case for the economic value of water for municipal and industrial uses. Their position relating to these uses is generally recognized in the laws and practices of the western states. Municipal use is a preferred use entitled to condemn water from other uses to meet its needs. It has a high capacity to pay and can afford the costs that are necessary to secure its water supply. Even in the arid states, municipal needs have been met at whatever costs may have been required. This was illustrated in early western development by the water supply built to supply Virginia City during its active mining days; in more recent years, where necessary, domestic water has been supplied to some areas by railroad transportation in tank cars.

The authors also discuss the use of water for irrigation and conclude that past policies have overemphasized the economic benefit of irrigation. There is much room for improvement in the standards that have been and are being used to determine the feasibility of irrigation projects. However, some of the conclusions expressed in this paper are not supported by the history of irrigation development.

The discussion of the classification of irrigable lands does not reflect the practices of recent years. In early projects errors were made in land classification and some projects failed when the lands were found to be unsuitable. Over thirty years ago the State Engineer of California required exclusion of substantial areas of low quality land as a condition for his approval of certain proposed water storage districts. More recently the Bureau of Reclamation has eliminated large areas of glacial till soil previously included in authorized projects in the Missouri River Basin.

1. Cons. Engr., Berkeley, Calif.

Distribution systems for irrigation need to serve compact areas if the cost of the system per acre served is to be kept within allowable limits. It may be to the advantage of a project to include lands of second or third quality if their incremental costs are less than the rates for water which such lands can pay.

In usual land classifications up to five or six classes are recognized. Class 1 land are areas having no essential defects; like the perfect man, such areas are rare. Some land classification systems assign percentage values to various factors. An area may be rated 80 per cent on soil texture, 80 per cent on topography and 80 per cent on crop adaptability. Instead of the result being an 80 per cent rating, these factors may be multiplied giving a final rating of about 51 per cent. The Modesto and Turlock Irrigation District are recognized to be among the most successful in California yet because their soils are sandy they are mainly rated as Class 3 in the "Storie Index" which has been extensively used in rating soils in California.

The classification of lands in California quoted in the authors' Table 2 is not representative of the results of recent detailed land classification. The State in its recent reports found about 20,000,000 acres in California suitable for irrigation if water could be supplied.

Some subsidy to irrigation has always been included in federal projects constructed under the reclamation law. The extent of such subsidies has been increased over the years since the reclamation act was passed in 1902. It now includes not only an interest subsidy over the present usual repayment period of 50 years but also, in recent projects, a large part of the construction cost allocated to irrigation is to be repaid by other project services.

Municipal and industrial uses on federal reclamation projects now pay the cost allocated to such uses with interest. There has been no need to extend subsidies to these uses, when they are included in irrigation projects, as they have been able to meet the full costs of their service. There has been and is no need to extend subsidies, either federal or state, to single purpose municipal water projects as the taxpayers in organizations supplying such water have the capacity to pay taxes or water tolls sufficient to meet their own costs.

There are ample grounds on which to disagree with much of the present policies and politics relating to federal subsidies to irrigation. The subsidies extended on some recently authorized irrigation units in basin wide projects exceed any realistic valuation of the indirect benefits which will result from their inclusion.

With California proposing to undertake construction of state projects there is a definite need for the state to get started on a more sound basis. However, the criticisms that may be made of current irrigation practices do not include depriving municipal and industrial uses of water they can use.

If the water supplies of the western states should be assigned and used for irrigation to the detriment of municipal and industrial uses, the concern of the authors would be well founded. As there are no programs in which such results are planned, the authors' paper serves to call attention to the greater value of use for municipal and industrial purposes and the advantages to irrigation of including such high ability to pay customers in multiple use projects.

M.
for flo
ported
is byp
shows
consid
types
the co
relati
greatl
Th
the au
undefi
is use
Fig. 7
0.038
mm.
Th
the w
If the
perm
or mo
ten pe
exten
facto
of Er
comm
knowl
may
age s
It
the p
which
these
The
surfa

a. P
1. Hy

LABORATORY RESEARCH ON INTERCEPTOR DRAINS[a]

Discussion by M. Maasland

M. MAASLAND,[1] M. ASCE.—This paper reports results on scale models for flow of water into interceptor drains. It includes checks of a formula reported by Donnan (1959) and extends the investigation to cases in which there is bypass flow underneath the drain. The paper is informative in that it shows that the relationships developed are valid for the range of conditions considered in the model experiments. The results are useful for certain types of drainage design. The fact that the relationships are found valid for the conditions considered by the authors does, of course, not imply that the relationships can be extrapolated to steeper slopes or to flow geometries greatly at variance with those in the experiments.

The writer is unfamiliar with the work of Maxis and Tsui referred to by the authors. However, it is obvious that the exponent n of Eq. 17, which is undefined in the paper, should equal 1 (one) if the Dupuit differential equation is used in unmodified form. It is observed that the equation as shown in Fig. 7 is not identical to Eq. 17. The reported hydraulic conductivity of 0.038 ft./hr. seems very low for a sand having a mean particle size of 2.72 mm.

The shape of the water table above the drain is studied in great detail but the water table below the drain is frequently of equal or greater significance. If there is bypass flow underneath the drain, particularly through highly permeable substrata below drain depth, the question arises whether a second or more drains will be needed further below. This leads to complex and often perplexing problems which are usually satisfactorily solved by gradually extending the drainage system as the need becomes evident. The most satisfactory analytical procedure in dealing with these problems is probably that of Ernst (1954), whose work is not available in the English language. As is common to many groundwater problems, his methodology requires detailed knowledge of the field conditions resulting in high cost of investigation which may or may not be justified by the cost of construction of the required drainage system.

It may be noted here that an exact solution for the problem considered in the paper under discussion is given by Dachler (1936) and by Kozeny (1953) which is obtained by a method involving the use of conformal mapping. Both these authors discuss the validity of the formula reported by Donnan (1959). The equation given by these authors can be extended to include the effect of surface-applied recharge by the simple transformation in the hodograph plane

a. Proc. Paper 2154, September, 1959, by Jack Keller and A. R. Robinson.
1. Hydr. Engr., Bureau of Reclamation, McCook, Nebr.

discussed by Engelund (1957). In that manner, an exact solution may be obtained for the shape of the water table, flow lines, and equipotential lines for inflow into flat drains embedded in a sloping impervious layer. This solution would be similar to the one given by Engelund (1951) for flat drains embedded in a horizontal impervious layer. An exact equation can thus be obtained for the water table which includes the effect of both a sloping impervious layer and surface-applied recharge. Another exact solution for flow into drains above a sloping impervious layer is given by Gustaffson (1946).

Solution of the steady state flow problem is only a beginning and is inadequate for most practical problems. Nonstationary flow over a sloping impervious layer is considered by Boussinesq (1877), Werner (1953, 1957), and others. Maasland (1958) reviews the derivation of Werner's differential equation. These equations, which are all based on the Dupuit assumption, are only valid for flow over a moderately sloping impervious layer and are subject to further restrictions due to the assumption of approximately lateral flow which prohibits consideration of the bypass flow underneath the drain. The equations 12 and 13 of Keller and Robinson are subject to severe restrictions for the same reasons, and caution should be exercised in applying these equations to field problems beyond the range of conditions considered in the experiment. Flow convergence near the drain cannot be overlooked and cannot be determined by the authors' methods without excessive effort.

It is, of course, clear that neither the differential equation nor the formula reported by Donnan (1957) and discussed by Todd and Bear (1959) are new or of recent date. In fact, the differential equation was first put forward and used by Boussinesq in 1877 and has been discussed in some detail by Forchheimer (1930). Boussinesq (1904) developed the theory of the flow of groundwater further and obtained the second Glover formula reported by Dumm (1954) as a special case of his general theory. In the latter work, Boussinesq also consideres the effect on the water table of intermittent recharge for which a more general theory was developed by Maasland (1959). The latter theory may also be used for flow over a sloping impervious layer if the Dupuit assumptions are applicable.

This discussion is not intended as a criticism of the interesting and useful work of the authors. However, the writer wishes to draw attention to the fact that there is a great deal of valuable information available in the literature which is being overlooked in present work.

REFERENCES

Boussinesq, J., Note sur le mouvement des eaux souteraines, "Essai sur la théorie des eaux courantes," 23, 242-281, 1877.

Boussinesq, J., Recherches théoriques sur l' écoulement des nappes d'eau infiltrées dans le sol et sur le débit des sources, Journ. Math. Pures et Appl., 10, 1-78, 1904.

Dachler, R., "Grundwasserströmung," Springer, Vienna, pp. 88-98, 1936.

Donnan, W. W., Drainage of agricultural lands using interceptor lines, Proc. ASCE, pp. 13-23, separate 1963, 1959.

Dumm, L. D., Drain spacing formula, Agr. Eng., 35, 726-730, 1954.

Engelund, F., Mathematical discussion of drainage problems, Trans. Danish Acad. Tech. Sci., no. 3, pp. 12-19, 1951.

Engelund, F., The water table in equilibrium with rainfall and irrigation, in: Drainage of agricultural lands, J. N. Luthin, ed., Agron. Monograph VII, Am. Soc. Agron., Madison, Wisc., pp. 128 and 129, 1957.

Ernst, L. F., Het berekenen van stationaire grondwaterstromingen welke in een verticaal vlak afgebeeld kunnen worden, Landbouwproefsta. en Bodemkundig Inst. T.N.O., Groningen, Netherlands (mimeo.), no. 3, 55 pp., 1954.

Forchheimer, Ph., Hydraulik, Teubner, Leipzig and Berlin, Germany, 3rd edition, 1930.

Gustaffson, Y. Untersuchungen über die stromungsverhältnisse in gedräntem, Boden. Acta An. Suecana, 2(1), pp. 157, Stockholm, Sweden, 1946.

Kozeny, J., Hydraulik, Springer, Vienna, Austria, pp. 411 and 412, 1953.

Maasland, M., Discussion of "Some problems in non-artesian groundwater flow," Trans. Am. Geophys. Union, 39, 738-740, 1958.

Maasland, M., Water Table Fluctuations Induced by Intermittent Recharge, Journ. Geophys. Res., 64, pp. 549-559, 1959.

Todd, D. K., and Bear, J., Discussion of "Drainage of Agricultural lands using interceptor lines," by W. W. Donnan, Proc. ASCE, 83, No. IR 3, pp. 113-115, 1959.

Werner, P. W., On non-artesian groundwater flow, Geofis. Pura Appl., 25, 37-43, 1953.

Werner, P. W., Some problems in non-artesian ground-water flow, Trans. Am. Geophys. Union, 38, 511-518, 1957.

M
pump
limit
The a
from
10^6 g
trans
limit
analy
In so
porte
P
exper
sure
As a
vanta
ing t
area
used
It
diam
state
in a
obse

a. E
1. E

AQUIFER TESTS IN THE SNAKE RIVER BASALT[a]

Discussion by M. Maasland

M. MAASLAND,[1] M. ASCE.—The paper contains interesting analyses of pumping tests at two sites and a sound discussion of the applicability and limitations of the theory of non-stationery flow of ground-water into wells. The authors state that the transmissibility of the Snake River basalt ranges from 1×10^5 gpd per foot to 1.8×10^7 gpd per foot and averages about 4×10^6 gpd per foot. Close reading of the article seems to indicate that the transmissibility effectively varies from zero to an as yet unknown upper limit. The authors are very careful in pointing out the limitations of the analyses and indicate that none of the wells tested had complete penetration. In some areas the transmissibility may be greatly in excess of the values reported.

Perhaps the authors would explain their reasons for making such detailed, expensive pumping tests which, in themselves, are no more than 'spot' measurements if the great areal extent of the Snake River basalt is considered. As a matter of fact, the writer wonders whether it would not have been advantageous to omit detailed tests in favor of collecting information concerning the discharge, drawdown, and general well performance over a larger area. Conclusions might be drawn from such information by the methods used by the authors for analyzing specific-capacity data.

It is stated at the bottom of page 55 that the area of basalt sampled has a diameter of roughly eight miles. This does not seem consistent with the statement in the preceding paragraph that there was no significant drawdown in a test well located 5,450 feet from the pump well. Justification for this observation is not clear.

---

a. Proc. Paper 2156, September, 1959, by W. C. Walton and J. W. Stewart.

1. Hydr. Engr., U. S. Bureau of Reclamation, McCook, Nebr.

M.
tion re
ful in
It i
areas
leachi
the so
gardi
consi
balan
is, wh
are a
on the
Of
page
could
tent t
the e
large
applie
ation
The w
rathe
of the
Infor
tems
As
to dat
The v
use a
meth
takes
tribu
gener

a. Pr
1. Hy

DRAINAGE IN THE COACHELLA VALLEY OF CALIFORNIA[a]

Discussion by M. Maasland

M. MAASLAND,[1] M. ASCE.—Mr. Weeks' paper contains valuable information regarding drainage practices in the Coachella Valley. The paper is helpful in familiarizing engineers with the practices used in a specific area.

It is clearly brought out that there is a need for subsurface drainage in areas where soil salinity is a problem. Further knowledge of the amount of leaching water required annually to maintain a satisfactory salt balance in the soil is urgently needed. Perhaps the author could give information regarding the quantity of water, in excess of the consumptive use requirements, considered necessary or desirable in the Coachella Valley to maintain such balance. Questions also arise as to the required frequency of leaching, that is, whether deep percolation losses occur after every irrigation, whether they are applied intentionally to achieve leaching or occur haphazardly depending on the irrigation pattern which the individual water user happens to follow.

Of particular interest are the recommended design criteria mentioned on page 86. It would be of great value to the profession if additional information could be made available regarding the adequacy of these criteria and the extent to which they agree with experience. The author does not state whether the empirical equation for q applies to 40-acre tracts only or is also used for larger areas and for the total length of drain in such areas. If the equation is applied to any size area, it would appear that this equation excludes consideration of the soil permeability and the thickness of the permeable stratum. The writer wonders whether drain spacings based solely on practicability rather than soil permeability are generally satisfactory. Perhaps the soils of the Coachella Valley are unusually uniform throughout the irrigated area. Information regarding possible over- and/or under-design of drainage systems thus laid out would be very worthwhile.

As indicated by Mr. Weeks, no satisfactory procedure has been developed to date for determining required drain spacings for irrigation agriculture. The writer has recently succeeded in developing a method which is easy to use and leads to spacings that are consistent with field experience. The methodology referred to is based on the concept of intermittent recharge and takes into account the total annual deep percolation loss as well as its distribution over the year. It is worth noting that spacings thus calculated are generally much wider than those calculated from the usual spacing formulas.

---

a. Proc. Paper 2158, September, 1959 by Lowell O. Weeks.

1. Hydr. Engr., U. S. Bureau of Reclamation, McCook, Nebr.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

VOLUME 84 (1958)

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867(ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876(WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(ST7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

VOLUME 85 (1959)

JANUARY: 1892(AT1), 1893(AT1), 1894(EM1), 1895(EM1), 1896(EM1), 1897(EM1), 1898(EM1), 1899(HW1), 1900(HW1), 1901(HY1), 1902(HY1), 1903(HY1), 1904(HY1), 1905(PL1), 1906(PL1), 1907(PL1), 1908(PL1), 1909(ST1), 1910(ST1), 1911(ST1), 1912(ST1), 1913(ST1), 1914(ST1), 1915(ST1), 1916(AT1)[c], 1917(EM1)[c], 1918(HW1)[c], 1919(HY1)[c], 1920(PL1)[c], 1921(SA1)[c], 1922(ST1)[c], 1923(EM1), 1924(HW1), 1925(HW1), 1926(PL1), 1927(HW), 1928(HW1), 1929(SA1), 1930(SA1), 1931(SA1), 1932(SA1).

FEBRUARY: 1933(HY2), 1934(HY2), 1935(HY2), 1936(SM1), 1937(SM2), 1938(ST2), 1939(ST2), 1940(ST2), 1941(ST2), 1942(ST2), 1943(ST2), 1944(ST2), 1945(HY2), 1946(PO1), 1947(PO1), 1948(PO1), 1949(PO1), 1950(HY2)[c], 1951(SM1)[c], 1952(ST2)[c], 1953(PO1)[c], 1954(CO1), 1955(CO1), 1956(CO1), 1957(CO1), 1958(CO1), 1959(CO1).

MARCH: 1960(HY3), 1961(HY3), 1962(HY3), 1963(IR1), 1964(IR1), 1965(IR1), 1966(IR1), 1967(SA2), 1968(SA2), 1969(ST3), 1970(ST3), 1971(ST3), 1972(ST3), 1973(ST3), 1974(ST3), 1975(ST3), 1976(WW1), 1977(WW1), 1978(WW1), 1979(WW1), 1980(WW1), 1981(WW1), 1982(WW1), 1983(WW1), 1984(SA2), 1985(SA2)[c], 1986(IR1)[c], 1987(WW1)[c], 1988(ST3)[c], 1989(HY3)[c].

APRIL: 1990(EM2), 1991(EM2), 1992(EM2), 1993(EW2), 1994(HY4), 1995(HY4), 1996(HY4), 1997(HY4), 1998(SM2), 1999(SM2), 2000(SM2), 2001(SM2), 2002(ST4), 2003(ST4), 2004(ST4), 2005(ST4), 2006(PO2), 2007(HW2)[c], 2008(EM3)[c], 2009(ST4)[c], 2010(SM3)[c], 2011(SM3)[c], 2012(HY4)[c], 2013(PO2)[c].

MAY: 2014(AT2), 2015(AT2), 2016(AT2), 2017(HY5), 2018(HY5), 2019(HY5), 2020(HY5), 2021(HY5), 2022(HY5), 2023(PL2), 2024(PL2), 2025(PL2), 2026(PP1), 2027(PP1), 2028(PP1), 2029(PP1), 2030(SA2), 2031(SA2), 2032(SA2), 2033(SA2), 2034(ST5), 2035(ST5), 2036(ST5), 2037(ST5), 2038(PL2), 2039(PL2), 2040(AT2)[c], 2041(PL2)[c], 2042(PP1)[c], 2043(ST5)[c], 2044(SA3)[c], 2045(HY5)[c], 2046(PP1), 2047(PP1).

JUNE: 2048(CP1), 2049(CP1), 2050(CP1), 2051(CP1), 2052(CP1), 2053(CP1), 2054(CP1), 2055(CP1), 2056(HY6), 2057(HY6), 2058(HY6), 2059(IR2), 2060(IR2), 2061(PO3), 2062(SM3), 2063(SM3), 2064(SM3), 2065(ST6), 2066(WW2), 2067(WW2), 2068(WW2), 2069(WW2), 2070(WW2), 2071(WW2), 2072(CP1)[c], 2073(IR2)[c], 2074(PO3)[c], 2075(ST6)[c], 2076(HY6)[c], 2077(SM3)[c], 2078(WW2)[c].

JULY: 2079(HY7), 2080(HY7), 2081(HY7), 2082(HY7), 2083(HY7), 2084(HY7), 2085(HY7), 2086(SA4), 2087(SA4), 2088(SA4), 2089(SA4), 2090(SA4), 2091(EM3), 2092(EM3), 2093(EM3), 2094(EM3), 2095(EM3), 2096(EM3), 2097(HY7)[c], 2098(SA4)[c], 2099(EM3)[c], 2100(AT3), 2101(AT3), 2102(AT3), 2103(AT3), 2104(AT3), 2105(AT3), 2106(AT3), 2107(AT3), 2108(AT3), 2109(AT3), 2110(AT3), 2111(AT3), 2112(AT3), 2113(AT3), 2114(AT3), 2115(AT3), 2116(AT3), 2117(AT3), 2118(AT3), 2119(AT3), 2120(AT3), 2121(AT3), 2122(AT3), 2123(AT3), 2124(AT3), 2125(AT3).

AUGUST: 2126(HY8), 2127(HY8), 2128(HY8), 2129(HY8), 2130(PO4), 2131(PO4), 2132(PO4), 2133(PO4), 2134(SM4), 2135(SM4), 2136(SM4), 2137(SM4), 2138(HY8)[c], 2139(PO4)[c] 2140(SM4)[c].

SEPTEMBER: 2141(CO2), 2142(CO2), 2143(CO2), 2144(HW3), 2145(HW3), 2146(HW3), 2147(HY9), 2148(HY9), 2149(HY9), 2150(HY9), 2151(IR3), 2152(ST7)[c], 2153(IR3), 2154(IR3), 2155(IR3), 2156(IR3), 2157(IR3), 2158(IR3), 2159(IR3), 2160(IR3), 2161(SA5), 2162(SA5), 2163(ST7), 2164(ST7), 2165(SU1), 2166(SU1), 2167(WW3), 2168(WW3), 2169(WW3), 2170(WW3), 2171(WW3), 2172(WW3), 2173(WW3), 2174(WW3), 2175(WW3), 2176(WW3), 2177(WW3), 2178(CO2)[c], 2179(IR3)[c], 2180(HW3)[c], 2181(SA5)[c], 2182(HY9)[c], 2183(SU1)[c], 2184(WW3)[c], 2185(PP2)[c], 2186(ST7)[c], 2187(PP1), 2188(PP2).

OCTOBER: 2189(AT4), 2190(AT4), 2191(AT4), 2192(AT4), 2193(AT4), 2194(EM4), 2195(EM4), 2196(EM4), 2197(EM4), 2198(EM4), 2199(EM4), 2200(HY10), 2201(HY10), 2202(HY10), 2203(PL3), 2204(PL3), 2205(PL3), 2206(PO5), 2207(PO5), 2208(PO5), 2209(PO5), 2210(SM5), 2211(SM5), 2212(SM5), 2213(SM5), 2214(SM5), 2215(SM5), 2216(SM5), 2217(ST8), 2218(ST8), 2219(ST8), 2220(EM4), 2221(ST8), 2222(ST8), 2223(ST8), 2224(HY10), 2225(HY10), 2226(PO5), 2227(PO5), 2228(PO5), 2229(ST8), 2230(EM4), 2231(EM4), 2232(AT4)[c], 2233(PL3)[c], 2234(EM4)[c], 2235(HY10)[c], 2236(SM5)[c], 2237(ST8)[c], 2238(PO5)[c], 2239(ST8), 2240(PL3).

NOVEMBER: 2241(HY11), 2242(HY11), 2243(HY11), 2244(HY11), 2245(HY11), 2246(SA6), 2247(SA6), 2248(SA6), 2249(SA6), 2250(ST9), 2251(SA6), 2252(SA6), 2253(SA6), 2254(SA6), 2255(SA6), 2256(ST9), 2257(ST9), 2258(ST9), 2259(ST9), 2260(HY11), 2261(ST9)[c], 2262(ST9), 2263(HY11), 2264(ST9), 2265(HY11), 2266(SA6), 2267(SA6), 2268(SA6), 2269(HY11)[c], 2270(ST9).

DECEMBER: 2271(HY12)[c], 2272(CP2), 2273(HW4), 2274(HW4), 2275(HW4), 2276(HW4), 2277(HW4), 2278(HW4), 2279(HW4), 2280(HW4), 2281(IR4), 2282(IR4), 2283(IR4), 2284(IR4), 2285(PO6), 2286(PO6), 2287(PO6), 2288(PO6), 2289(PO6), 2290(PO6), 2291(PO6), 2292(SM6), 2293(SM6), 2294(SM6), 2295(SM6), 2296(SM6), 2297(WW4), 2298(WW4), 2299(WW4), 2300(WW4), 2301(WW4), 2302(WW4), 2303(WW4), 2304(HW4), 2305(ST10), 2306(CP2), 2307(CP2), 2308(ST10), 2309(CP2), 2310(HY12), 2311(HY12), 2312(PO6), 2313(PO6), 2314(ST10), 2315(HY12), 2316(HY12), 2317(HY12), 2318(WW5), 2319(SM6), 2320(SM6), 2321(ST10), 2322(ST10), 2323(HW4)[c], 2324(CP2)[c], 2325(SM6)[c], 2326(WW4)[c], 2327(IR4)[c], 2328(PO6)[c], 2329(ST10)[c], 2330(CP2).

---

c. Discussion of several papers, grouped by divisions.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1960

PRESIDENT

FRANK A. MARSTON

VICE-PRESIDENTS

Term expires October, 1960:
PAUL L. HOLLAND
LLOYD D. KNAPP

Term expires October, 1961:
CHARLES B. MOLINEAUX
LAWRENCE A. ELSENER

DIRECTORS

Term expires October, 1960:
PHILIP C. RUTLEDGE
WESTON S. EVANS
TILTON E. SHELBURNE
CRAIG P. HAZELET
DONALD H. MATTERN
JOHN E. RINNE

Term expires October, 1961:
THOMAS J. FRATAR
EARL F. O'BRIEN
DANIEL B. VENTRES
CHARLES W. BRITZIUS
WAYNE G. O'HARRA
FRED H. RHODES, JR.
N. T. VEATCH

Term expires October, 1962:
ELMER K. TIMBY
SAMUEL S. BAXTER
THOMAS M. NILES
TRENT R. DAMES
WOODROW W. BAKER
BERNHARD DORNBLATT

PAST PRESIDENTS

Members of the Board

LOUIS R. HOWSON

FRANCIS S. FRIEL

EXECUTIVE SECRETARY
WILLIAM H. WISELY

TREASURER
E. LAWRENCE CHANDLER

ASSISTANT SECRETARY
E. LAWRENCE CHANDLER

ASSISTANT TREASURER
ENOCH R. NEEDLES

PROCEEDINGS OF THE SOCIETY

HAROLD T. LARSEN
Manager of Technical Publications

PAUL A. PARISI
Editor of Technical Publications

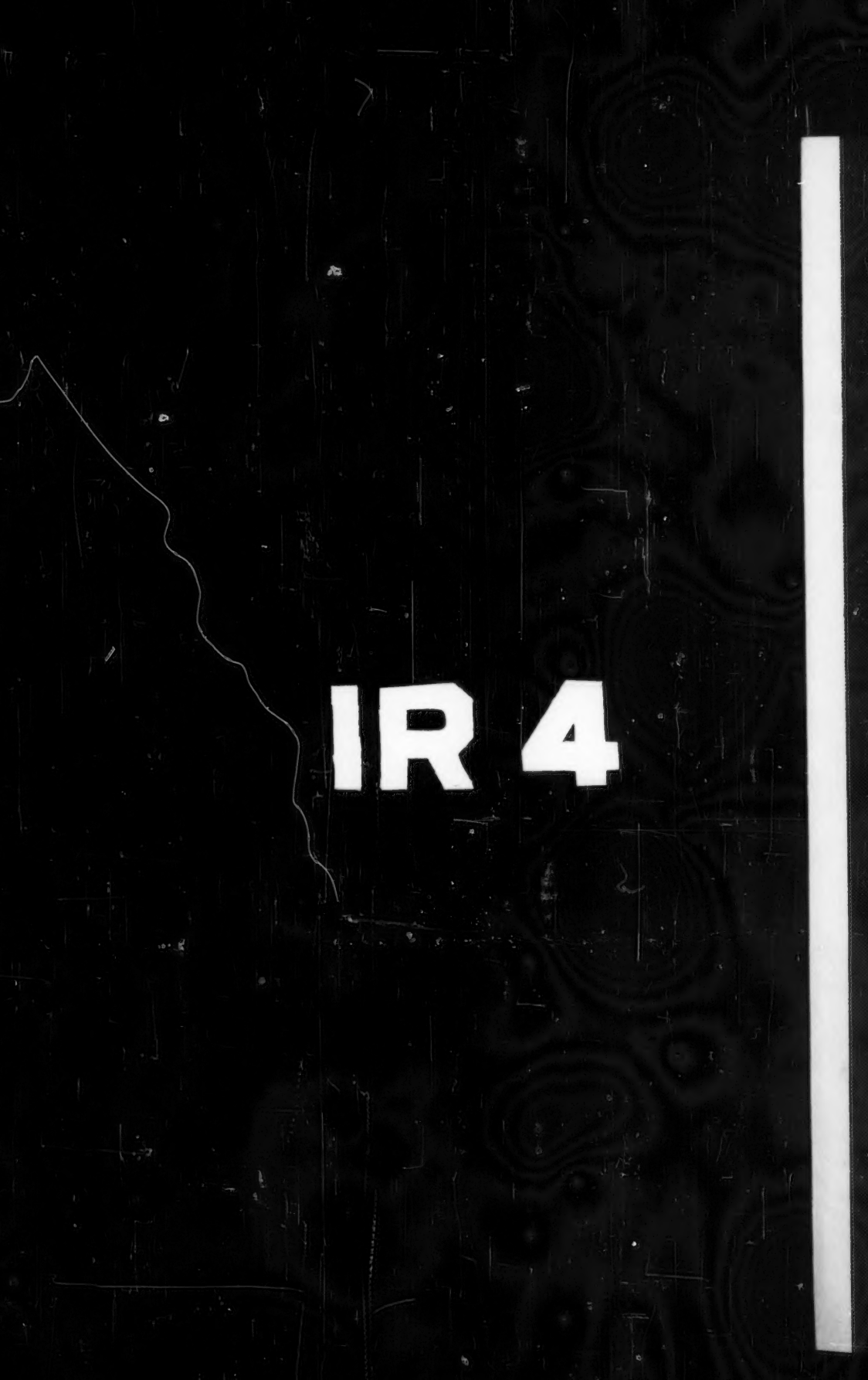
MARVIN L. SCHECHTER
Associate Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

PHILIP C. RUTLEDGE, *Chairman*

THOMAS M. NILES, *Vice-Chairman*

TILTON E. SHELBURNE
WESTON S. EVANS
WAYNE G. O'HARRA
BERNHARD DORNBLATT


IR 4

DECEMBER 1959 — 43 NO. IR 4
VOLUME 85 PART 2

Your attention is invited

NEWS OF THE IRRIGATION AND DRAINAGE DIVISION OF ASCE

JOURNAL OF THE IRRIGATION AND DRAINAGE DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

NEWS

December, 1959

EXECUTIVE COMMITTEE, IRRIGATION AND DRAINAGE DIVISION, ASCE

John H. Bliss, Chairman
125 N. Castillo St., Santa Fe, N. M.
Kenneth Q. Volk, Vice-Chairman
7024 Melrose Avenue, Los Angeles 38, Calif.
William W. Donnan, Secretary
P. O. Box 629, Pomona, Calif.
N. A. Christensen, (Cornell University)
412 Haushaw Road, Ithaca, New York
Herbert E. Prater, (Bureau of Reclamation)
2001 S. Madison St., Denver 10, Colo.
John E. Rinne, (Contact member from Board of Direction)
25 Van Tassel Lane, Orinda, Calif.
Carl R. Wilder, Newsletter Editor
3223 S. Columbine St., Denver 10, Colo.

CALENDAR OF COMING MEETINGS

March 7-11, 1960. National Convention, ASCE, Jung Hotel, New Orleans, La. Irrigation and Drainage Division plans to hold three half-day sessions as follows: Irrigation and Drainage in Humid Areas; Humid area water rights; Drainage.

June 20-25, 1960. National Convention, ASCE, Reno, Nevada. The Irrigation and Drainage Division sessions at this convention will constitute its technical conference for 1960. Plans have been tentatively completed for two half-day sessions on de-salinization, and half-day sessions on drainage and water conservation are being planned. It also is hoped that the division will sponsor one of the luncheons.

Get in touch with one of the following members of our committee on Sessions Programs if you would like to offer a paper or discussion at any of these or other I. & D. Programs.

Note: No. 1959-43 is part of the copyrighted Journal of the Irrigation & Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 85, IR 4, December, 1959.

Copyright 1959 by the American Society of Civil Engineers.

N. A. Christensen, Chairman, 712 Haushaw Road, Ithaca, N. Y.
Herbert E. Prater, Vice-Chairman, 2001 S. Madison St., Denver 10, Colo.
Governor George D. Clyde, 1747 Browning Ave., Salt Lake City, Utah
Dr. O. W. Israelsen, 485 East 6th North St., Logan, Utah

Chairmen of other standing committees of the Irrigation and Drainage Division are:

Committee on Publications: Dean F. Peterson, Jr., Utah State University, Logan, Utah.
Committee on Cooperation with Local Section: S. Mark Davidson, 2432 S. Jasmine St., Denver 22, Colo.
Committee on Consolidation and Progressive Betterment of Old Irrigation Systems: A. Alvin Bishop, Utah State University, Logan, Utah
Committee on Drainage of Irrigated Lands: E. W. Elliott, 9801 Salem Road, N. E., Albuquerque, N. M.
Committee on Ground Water: Harvey O. Banks, Dept. of Water Resources, Sacramento, Calif.
Committee on Irrigation and Drainage Practices in Humid Areas: Marion C. Boyer, 1330 W. Michigan St., Room 377, Indianapolis, Indiana
Task Group on Water Rights Laws in States in Humid Areas: James I. Seay, Jr., 516 Goodwyn Inst. Bldg., Memphis, Tenn.
Committee on Research: Gerald B. Keesee, Bureau of Indian Affairs, Box 912, Gallup, N. M.
Committee on Water Supply and Conservation: Harry F. Blaney, 215 West 7th St., Los Angeles 14, Calif.
Task Group on Methods of Conserving Water: Arthur E. Bruington, 636 W. Hermosa Ave., San Gabriel, Calif.
Task Group on Consumptive Use of Water by Irrigated Crops and Native Vegetation: Harry F. Blaney.
Task Group on Re-Use of Drainage Water and Water Reclamation: Lloyd E. Myers, Jr., Box 815C, Route 2, Tempe, Ariz.
Task Group on Water Management: Leonard Schiff, 2219 Lester St., Bakersfield, Calif.
Task Group on Water Quality: P. H. McGauhey, 6819 Snowden Ave. El Cerrito, Calif.

These men are constantly in need of help from other society members. Why not volunteer your talents to the one heading the committee that is working in your field of interest?

RECENT ACTIVITIES

During the last week of August 1959, the Irrigation and Drainage Division cooperated with the American Meterological Society in sponsoring a national conference on "Weather Modification by Artificial Means." This three-day meet attracted over one hundred registrants who joined with nationally-recognized experts in studying and discussing this important and fascinating subject. Considerable evidence was presented to show that precipitation can be and has been increased by various techniques. Nevertheless most speakers felt compelled to qualify their statements by acknowledging that some or all of the increases possibly would have occurred anyway.

Robert D. Elliott, President of North American Weather Consultants and co-chairman of the conference, pointed out that the value of any increase in precipitation so far outweighs the cost of the artificial measures taken to force such an increase that it is well worth the effort. The water in a 10 per cent precipitation or snowpack increase is worth 10 to 100 times more than the cloud-seeding costs, he said.

The Executive Committee appointed a special sub-committee of the Committee on Publications to edit and compile the papers of this conference. Subject to approval of the AMS this sub-committee will be jointly headed up by Harris R. McDonald, ASCE and Norman J. MacDonald, AMS.

* * * * *

The Washington National Convention of ASCE, in session as this is being written, includes 3 half-day sessions sponsored by the Irrigation and Drainage Division. The general theme is "World Wide Picture of Irrigation." The impressive list of speakers includes a number of ASCE members relating their personal overseas experiences in more than a dozen countries.

* * * * *

The U. S. National Committee of the International Commission on Irrigation and Drainage is submitting 18 papers for the Fourth Congress of ICID to be held in Madrid, Spain, in June 1960. Most of these were presented at the May 1959 Conference of USICID in Reno, Nevada. Responsibility for this conference and for submitting papers for the Fourth Congress rests with the Technical Activities Committee, of which C. W. Thomas, FASCE, is chairman. Charles R. Maierhofer, F. ASCE, is chairman of the USICID Executive Committee. Wilbur A. Dexheimer, F. ASCE, retired Commissioner of Reclamation, is international president of I.C.I.D.

* * * * *

The Committee on Ground Water met in Denver, August 26, 1959. Since much of the material originally programmed for the ASCE manual on ground water has recently been made available through the publication of texts on ground water, it was resolved "to rename the manual, 'Manual of Ground Water Basin Management', particularly slanted toward management aspects of ground water operations; to eliminate the detailed material on hydraulics of underground flow; the discussion of water quality to be principally concerned with the problems of maintenance of quality rather than with detailed discussion of quality factors and standards as an end in themselves." It is now planned that all material for the nine chapters of this manual will be in the hands of Chairman Harvey Banks by March 1, 1960.

* * * * *

The first monthly meeting of the Colorado Section Hydraulics and Irrigation and Drainage Divisions for the current "activity" year took place September 23, 1959. Charles G. Fisk, water rights engineer for the Denver (Colo.) Water Board, discussed "Water Supply for the Denver Metropolitan Area." He related the story of the combining of a number of independent water companies

into the Denver water system, the continually expanding program of acquiring water rights and providing reservoirs for storage of water supplies, and outlined the Water Board's program for future expansion of the system to keep up with the Denver area's growth.

The October joint meeting of these divisions featured a discussion by William J. Frederick of the Soil Conservation Service on "Rapid Pump Test Method for Drain Yield Estimates."

* * * * *

The Executive Committee met in Denver in August. In addition to organizational matters in connection with the completion of a term on the committee by Dean H. T. Person, and starting a new term by Herb Prater, the committee acted on the following matters of general interest:

Harris McDonald of the Bureau of Reclamation was appointed a regular member of the Committee on Publications, and Gilbert Levine, of Cornell University was appointed an advisory member.

The committee took note of the excellent work completed to date by the Committee on Research under the leadership of Chairman G. B. Keesee. His committee now is ready to submit a priority list of subjects or fields needing research to sponsors who might wish to promote or participate in them.

It was agreed that the June 1960 Reno National Convention would be the Irrigation & Drainage Division's technical conference for that year. The April 1961 Phoenix National Convention also has been tentatively designated as our technical conference for that year.

The Committee on Irrigation and Drainage Practices in Humid Areas submitted to the executive committee its proposal to prepare a manual. (See September Newsletter, pages 4 and 5) The Executive Committee approved a previously submitted outline, and suggested a course of action for this committee's future activities.

The Committee on Drainage of Irrigated Lands was reorganized. Edwin W. Elliott, USBR, Albuquerque, is the new chairman. Committee members are Charles R. Maierhofer, William W. Donnan, and Lyman A. Willardson. O. W. Israelsen is an advisory member. This committee will concentrate on the preparation and presentation of technical reports, papers and symposiums on drainage. Half-day sessions at the April 1961 Phoenix and February 1962 Houston conventions are being planned.

PUBLICATIONS AVAILABLE

"Can Man Develop a Permanent Irrigation Agriculture?" Proceedings of the First Intersociety Conference on Irrigation and Drainage," San Francisco, April 1957. These proceedings were edited by Robert M. Hogan, Chairman of the conference, and published by USICID with assistance from the National Science Foundation. Twenty-six valuable papers are included. Copies of the proceedings are avilable, at $4.50 each, from USICID, P.O. Box 7826, Denver 15, Colo.

Proceedings of the Seventh Hydraulics Conference of the Iowa Institute of Hydraulic Research, are available from the Department of Publication, State University of Iowa, Iowa City, at $3.50 per copy. The 306-page volume consists of the 14 papers and dinner address which were presented at the 1958

conference. A detailed list of the subjects included may be obtained from the Department of Publication.

Soil Science is a monthly journal published under the editorial direction of the Department of Soils, Rutgers University. It has been serving persons interested in soils since 1916, and now has over 2,600 subscribers. During a recent 12-month period it published 111 papers, 37 of them from foreign contributors. Research papers for publication may be submitted to Dr. Firman E. Bear, Rutgers University, New Brunswick, New Jersey. Subscriptions, at $5 per volume of 6 months or $10 per year should be sent to the Williams and Wilkins Co., 428 East Preston Street, Baltimore 2, Maryland.